Digital methods for agro-monitoring and nutrient load management in the Russian part of the Baltic Sea catchment area

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Abstract. The article describes the basic requirements for an interactive programme designed for agro-monitoring and nutrient load management in the Russian part of the Baltic Sea catchment area within the borders of the Leningrad Region. The programme will monitor the farm generation of nutrients (nitrogen and phosphorus) in the organic fertilisers and create the logistical scheme of their application with due account for environmental and economic factors. The functional objectives of the interactive programme are to receive the relevant source information on the region, agricultural organisations, applied animal/poultry manure handling technologies, and manure storage types; to visualize all agricultural organizations on a digital map: location, name, specialisation, animal stock, available agricultural land; to calculate and display the current situation in agricultural enterprises: amount of organic fertiliser received, land sufficiency for all organic fertiliser application, and required volume of manure storages and composting pads; to calculate and display the forecast situation in agricultural organizations and to create the electronic passports of farms, districts and the whole Leningrad Region including the logistics of organic fertilisers distribution from supplier farms to consumer farms considering the nutrient load standards and the data on the nutrient load distribution within the boundaries of agricultural lands in the catchment area.

1 Introduction

Nutrient load monitoring and relevant abatement measures are among the priority tasks of the joint environmental efforts in the Baltic Sea Region. Agricultural production is the key source of diffuse nutrient (nitrogen and phosphorus) loading on the water bodies [1-3], with the main contributors being livestock and poultry farms, soil tillage and crop cultivation practices. Soil, mineral and organic fertilisers are generally regarded as the sources of nitrogen and phosphorus input.

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In the Leningrad Region alone, large-scale agricultural enterprises annually produce above 5 million tons of organic fertilisers based on animal/poultry manure containing above 30 thousand tons of nitrogen and 6 thousand tons of phosphorus [4]. These organic fertilisers should be applied to the agricultural land in compliance with environmental safety standards to increase soil fertility [5, 6, 7].

The intensive farming features a specific livestock density of above 1.5 LU per one hectare of cultivated land. Under these conditions, the monitoring of the nitrogen and phosphorus generation in the organic fertilizers becomes especially urgent as well as establishing the logistic pattern of their application with due account for environmental and economic factors.

The purpose of the study was to establish the basic requirements for an interactive programme created for the monitoring of livestock/poultry waste handling and coordination of organic fertilisers application on the agricultural lands.

The digital tool in the interactive programme form is designed for information support of the executive authorities and heads of agricultural enterprises in terms of improving the environmental compliance and production efficiency associated with preparation and field application of organic fertilisers.

2 Methods

The study considers the Leningrad Region with above 800 agricultural enterprises. However, about 90% of the gross output is produced by 137 large-scale agricultural organizations: 96 cattle farms, 8 pig-breeding complexes, 11 poultry farms, and 20 crop-growing farms. Two enterprises are of a mixed type (cattle and pigs). All enterprises are classified according to either their need for organic fertilisers (consumer farms) or their potential to transfer the organic fertiliser surplus (supplier farms).

The digital maps based on a selected geographic information system will be used to position the farms and to determine the inter-farm relationships in terms of organic fertilizer distribution. This way the programming resources are combined with spatial visualisation, and the agro-monitoring and nutrient load management are made interactive.

The mathematical model for limiting the nutrients introduction per one hectare of agricultural land was adopted as the basis to create a forecasting system and a logistic scheme for organic fertilisers distribution.

The limiting factor in the fertiliser application dose is total nitrogen (170 kg/ha) and total phosphorus (25 kg/ha). When one of the indicators reaches the limit value, the programme will give a signal. The indicator (total nitrogen or total phosphorus), the limit value of which is reached first, is considered the most significant in the calculation of the organic fertilizer application dose.

The amount of total nitrogen in the resulting organic fertiliser $M_1$ (t/year) is calculated by the formula (1):

$$M_1 = \left( \frac{M_m \cdot K_1 + M_{ma} \cdot K_2}{100} \right) \cdot \frac{100 - K_3}{100}$$

Where $M_m$ – amount of animal/poultry manure, t/year;

$K_1$ – coefficient of total nitrogen content in animal/poultry manure; it differs for each type of initial raw material, %;

$M_{ma}$ – amount of moisture absorbing material, t/year;

$K_2$ – coefficient of total nitrogen content in the moisture absorbing material; it differs for each material, %;

$K_3$ – coefficient of total nitrogen loss during the mixture processing into a solid/liquid organic fertiliser; it differs for particular processing technologies, %.
The amount of total nitrogen, which can be applied to the own agricultural lands of the farm, $M_2$ (t/year) is calculated by formula (2):

$$M_2 = S \cdot \frac{K_4}{1000}$$  \hspace{1cm} (2)

Where $S$ – agricultural land area, ha;

$K_4$ – coefficient, which takes into account the limits of total nitrogen application under the particular cultivated crop, kg/ha.

The amount of total phosphorus in the resulting organic fertiliser and the amount of total phosphorus, which can be applied to the own agricultural lands of the farm, are calculated by the similar formulas.

When creating an interactive programme, a structured database system will be used to automate the process of agro-monitoring and the nutrient load management (Figure 1) [8-10].

**Fig. 1.** A structured database system for the agro-monitoring and the nutrient load management

B1, B2...B36 - intermediate output parameters, which are shown in the electronic passports of farms and are used in the further calculations;

P1, P2...P5 – intermediate estimated parameters, which are not shown in the electronic passports of farms;

DB – database of coefficients used in the calculations.

3 Results and Discussion

Our previous studies identified five main functional objectives in the interactive programme.
Objective 1 was addressed with the activity analysis of agricultural organizations in the region including the animal/poultry manure processing technologies, and the types of manure storage facilities in place. Table 1 shows the basic initial data acquired from the relevant official statistical sources for future modelling.

**Table 1. Initial data by the districts of the Leningrad Region**

| District                  | Total cattle stock, head | Total pig stock, head | Total poultry stock, head | Total area of agricultural land, ha |
|---------------------------|--------------------------|-----------------------|---------------------------|-------------------------------------|
| Boksitogorskij District   | 317                      | 0                     |                           | 250                                 |
| Volosovskij District      | 23801                    | 0                     |                           | 36547                               |
| Volkhovskij District      | 13136                    | 5430                  |                           | 11584                               |
| Vsevolozhskij District    | 12778                    | 0                     |                           | 9513                                |
| Vyborgskij District       | 9581                     | 6424586               |                           | 8374                                |
| Gatchinskij District      | 18148                    | 2983000               |                           | 26299                               |
| Kingiseppskij District    | 8256                     | 0                     |                           | 10263                               |
| Krishskij District        | 7962                     | 0                     |                           | 8678                                |
| Kirovskij District        | 1259                     | 1893700               |                           | 1881                                |
| Lodeinopolskij District   | 1606                     | 6110                  |                           | 2683                                |
| Lomonosovskij District    | 8631                     | 6249                  |                           | 13010                               |
| Luzhskij District         | 19399                    | 29200                 |                           | 21102                               |
| Priozerskij District      | 21991                    | 3552                  |                           | 19690                               |
| Slantsevskij District     | 5231                     | 0                     |                           | 6948                                |
| Tikhvinskij District      | 3837                     | 0                     |                           | 5478                                |
| Tosnenskij District       | 10882                    | 120557                |                           | 15868                               |
| Total                     | 166815                   | 171118                |                           | 161621                               |

Cattle farms produce two types of manure – solid or liquid manure, depending on loose or tied animal housing technology [11, 12]. Pig-breeding complexes produce slurry and modern poultry factories produce mainly the solid poultry manure [13, 14].

Solid animal/poultry manure is processed into a solid organic fertiliser by passive composting on the open water-proof (concrete) pads. Liquid manure (slurry) is processed into a liquid organic fertiliser in the storage by the long-term storing (maturing).

Solid and liquid organic fertilisers are applied to the agricultural land to improve soil fertility. The application dose and the required land area are calculated from the total nitrogen and total phosphorus content in the organic fertiliser.

To address Objective 2, all agricultural enterprises are shown on an interactive map: location, name, specialisation, animal/poultry stock, available agricultural land area. All enterprises are divided into 5 groups: cattle farms, pig farms, poultry farms (chickens and quail), crop growing farms and mixed-type farms (cattle and pigs). Each group of agricultural enterprises has its own graphic designation. The interactive programme algorithm provides for the export filter of individual groups of enterprises.

To address Objective 3, the current situation on the agricultural enterprises is calculated and visualised by digital methods with the use of developed mathematical models: amount of animal/ poultry manure produced, amount of organic fertiliser received, the sufficiency of land for all organic fertilisers application, and required volume of manure storages and composting pads. The results obtained make it possible to manage the nutrients and to monitor the expected reduction of diffuse load from agricultural production on the Baltic Sea.

Objective 4 is to calculate and display the forecast situation on the agricultural enterprises using the obtained agro-monitoring data and including the created logistical scheme of
organic fertilisers distribution from supplier farms to consumer farms with due consideration for the limiting nutrient loads.

As a result, all organic fertilisers produced are distributed over the agricultural land that reduces the diffuse load in the Baltic Sea Region. The nutrients are managed depending on specified conditions by changing the optimisation criteria in the relevant logistic model.

According to Objective 5, the results are displayed in the form of electronic passports of agricultural organizations, the districts and the entire region under study, taking into account the logistics of organic fertilisers distribution and the data on the nutrient loads within the agricultural land in the Baltic Sea catchment area.

Based on implementation of the above objectives, an interactive computer programme for agro-monitoring and organic fertilisers distribution will be designed.

A review of related studies supported the importance and current need for such a tool to improve the environment in the Baltic Sea Region and to make adequate decisions associated with the nutrient management [15-20].

4 Conclusions

The study substantiated the basic requirements for an interactive programme designed for agro-monitoring and nutrient load management in the Russian part of the Baltic Sea catchment area within the borders of the Leningrad Region.

An interactive programme will calculate the current and forecast situation on 137 agricultural organizations in the region, which produce above 5 million tons of organic fertilisers per year, with the nitrogen content being of above 30 thousand tons and the phosphorus content being of 6 thousand tons. The limiting factors in the fertiliser application dose are total nitrogen (170 kg/ha) and total phosphorus (25 kg/ha). When one of the indicators reaches the limit value, the programme will give a signal.

The functional objectives of the interactive programme are (1) to receive the relevant source information on the region, agricultural organisations, applied animal/poultry manure handling technologies, and manure storage types; (2) to visualize all agricultural organizations on a digital map – their location, name, specialisation, animal stock, available agricultural land; (3) to calculate and display the current situation in agricultural enterprises, namely the amount of organic fertiliser received, the land sufficiency for all organic fertiliser application, and the required volume of manure storages and composting pads; (4) to calculate and display the forecast situation in agricultural organisations including the logistics of organic fertilisers distribution from supplier farms to consumer farms considering the nutrient load standards; (5) to create the electronic passports of farms, districts and the whole Leningrad Region with due account for the logistics of organic fertilisers distribution and the data on the nutrient load distribution within the boundaries of agricultural lands in the Baltic Sea catchment area.

Implementation of these objectives into a computer interactive programme will create a tool for the information support of the executive authorities and heads of agricultural enterprises in terms of improving the environmental compliance and production efficiency associated with agricultural application of organic fertilisers.

The main requirements for the programme were developed with the approval of the Committee for Agroindustry and Fisheries Complex of the Leningrad Region and under support of the project “Introduction of the ecological system of agriculture is the basis for sustainable development of border rural area – EcoAgRas” of the South-East Finland - Russia CBC 2014-2020 Programme (Grant contract №17086-LIP1601-KS1441).
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