Bulgarian Journal of Agricultural Science, 28 (No 1) 2022, 49–54

Methodology of ecological-and-economical assessment of manure disposal systems

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Abstract

Ivanov, Y. A., Gridnev, P. I. & Gridneva, T. T. (2022). Methodology of ecological-and-economical assessment of manure disposal systems. *Bulg. J. Agric. Sci., 28 (1)*, 49–54

The method of ecological-and-economic assessment of manure utilization systems for livestock enterprises of all types of production located in either natural-and-climatic conditions is proposed. Methodology of this method development is based on scientific knowledge on manure cleaning and for use preparing are based, producing organic fertilizers' quality, and their impact on soil fertility. In addition, the environment's protecting from pollution's requirements are taken into account. The proposed method allows on a complex criteria to offer – minimum costs for required amount of nutrients and organic matter per unit area for the planned crop yield, in compliance with environmental protection requirements. The use of science-based manure disposal systems will ammonia and greenhouse gases emissions into the atmosphere significantly reducing, as well as the damage caused by the humus' losses in soils are up to 700.0 thousand of rubles per ha.

Keywords: manure, organic fertilizer, ecological safety, ammonia emission

Introduction

Due to the world population's growth, the global warming likelihood in recent years, the requirements for all types of enterprises as to greenhouse gas into the atmosphere emissing, soil fertility preserving have increased (Kammann et al., 2017; Chen et al., 2016; Samer, 2016). This fully applies to agricultural production, in particular to manure disposal systems. Due to their imperfection, there are significant greenhouse gas emissions into the atmosphere and losses of plant nutrients from manure are observed, and manure complete utilization in the organic fertilizers' form is not ensured. The lost economic benefit from manure fertilizer resources' inefficient use up to 165 billion rubles per year, including soil fertility losses up to 700 thousand rubles per ha is estimated (Awasthi et al., 2019; Gusev, 2013; Ivanov & Mironov, 2018; Szanto et al., 2006). Due to the latter circumstances, it is not possible soil fertility to maintain. The technological and technical solutions for manure utilization systems' choice is made without the manure quantity and quality strict consideration obtained, the areas natural-and-climatic features where the livestock enterprise is located, crop production quantity and quality, and the amount of greenhouse gas emissions into the atmosphere (Briukhanov, 2016; Briukhanov et al., 2016; Donnik & Voronin, 2016). In this regard, research aimed at a mechanism for possible manure disposal systems' technological and technical solutions options complex assessment creating is relevant.

The aim of this research work is a methodology for ecological-and-economical assessment of manure utilization systems, which use will allow at either livestock enterprise design stage, taking into account the region specific natural-and-climatic features, highly effective ecologically safe technological and technical solutions for the manure as organic fertilizers using to justify.

Materials and Methods

Either manure disposal system is related to biotechnologies (Briukhanov, 2019; Karasik, 2020; Management, 2017). Its implementation is carried out as a result of biological processes, starting with the animal's body and ending with humus in the soil formation. An assessment of such technologies effectiveness is possible only if many factors of influence are taken into account. The scientific basis of biological processes that are occurring in the animal's body, manure storage, accumulation and processing by various methods, and organic fertilizers' humification in the soil – have determined this research methodology (Ba, 2020). The manure disposal systems' creation and operation it requires certain costs, each of them has its characteristics for harmful substances emissions into the atmosphere and ground water, produced organic fertilizers' quantity and quality, which have different returns in different natural-and-climatic conditions. Only complex accounting of all the above mentioned factors by a single way this criterion will allow an objective assessment of the various options to consider (Aboltins, 2019; Karasik, 2020; Man-Agency, 2017).

The structure of the proposed ecological-and-economic assessment of manure disposal's various systems consists of six blocks (Figure 1).

Having information on the natural-and-climatic characteristics of livestock enterprise area is located, crop rotation's expected structure, produced organic fertilizers' quality and quantity, there in block four by calculation, we define the S_k area, that can be fertilized with this organic fertilizer. To meet the soil fertility maintenance requirements, the organic compensating materials' purchase and application norms and costs − σ_2, mineral fertilizers − σ_3, missing nutrients and lime fertilizers compensating − σ_4, weed control measures implementation − σ_5 are determined. In addition, the biological yield and additional production increasing is estimated− σ_6, it provided when soil fertility is preserved.

In the fifth block of ecological-and-economic assessment of manure disposal systems, the emissions of four harmful gases into the atmosphere calculation at all technological operations has been done. Environmental damage is determined – as σ_7 (Table 1).

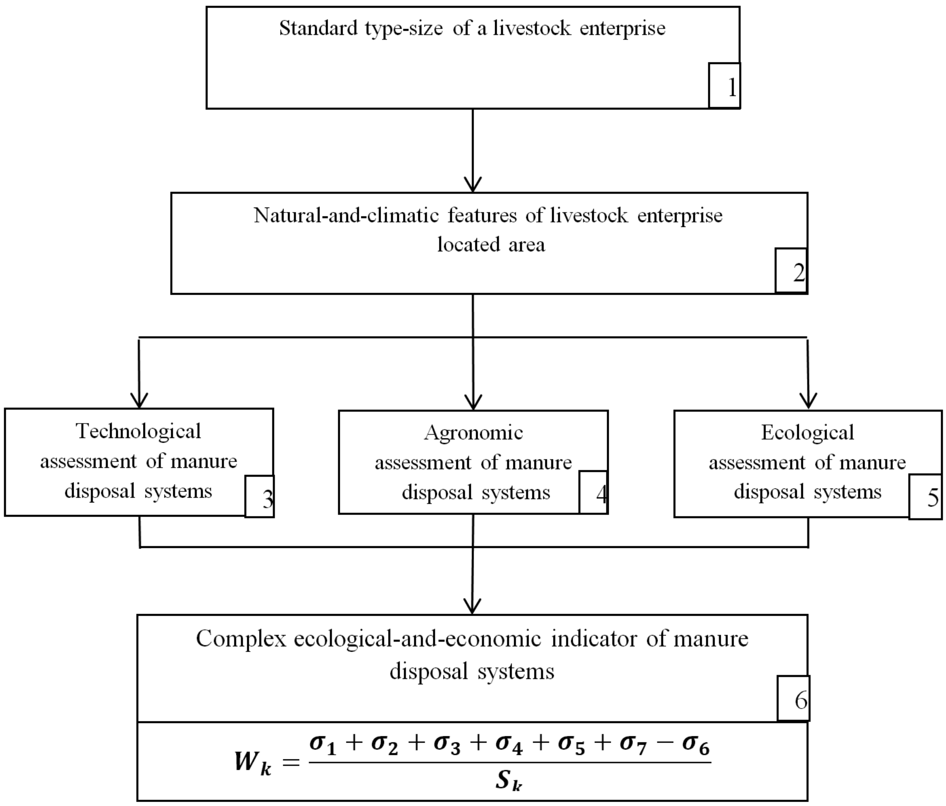

Fig. 1. Structure of ecological-and-economic assessment of the manure disposal system

Table 1. Global warming potential (PGP) and three greenhouse gases' total ecological damage

Greenhouse gas	Chemical structure of gas	Total ecological damage, € /t	PGP equivalent to CO_2
Carbon dioxide	CO_2	44	1
Methane	CH_4	296	23
Nitrous oxide	N_2O	24600	296

The PGP shows the degree of equal masses of greenhouse gases' impact on the atmosphere, taking into account the lifetime of each of them. Thus, the emissions of low-mass greenhouse gases that are more toxic or a longer period in the atmosphere getting additional "weight", have been taken into account by their PGP have had.

Losses of nitrogen and carbon of the abovementioned gases' form depend on the animals' housing technologies, given technological and technical decisions for all processes, natural-and-climatic features of the livestock enterprise's located area. They must be taken into account at particular facility producing (Awasthi, 2019; Chen, 2018; Szanto, 2006).

All costs associated with the organic fertilizers' produce and use, compensating materials and mineral fertilizers' purchase and introduction, environment damage from all types of fertilizers' production and use in value terms are determined, they can be analyzed both separately and in their total amount.

A detailed quantitative assessment of all possible technological and technical solutions for the organic fertilizers' production and use based on manure, it is proposed according to a complex criterion that has the ratio form of the total complex costs for all technological processes to the fertilized area at the fertilizer application rate for the planned yield's implementation to be made:

$$W_k = \frac{\sum_{m=1}^{r} \sigma_m}{\sum_{n=1}^{i} S_n} \rightarrow min \quad (1)$$

where: σ_m – are annual complex costs of the κ-research technology at the r- number of operations, th.of rubles., S_n – is the area of agricultural land with the i-number of crops in the crop rotation, where the fertilizer obtained by the κ research technology on a specific livestock enterprise is used, ha.

Complex costs depend on: capital investment (K, rubles) in machinery, equipment, construction part, given by E dimensionless efficiency coefficient to one year of using ration, and direct operating costs Э. There in operating costs, all the above mentioned costs with the complete manure disposal associated are included:

$$\sigma_k = \sum_{m=1}^{r} (K_m \cdot E + Э_m) \rightarrow min \quad (2)$$

The objective function (1) tends to a minimum at the denominator tends to a maximum, when the soil fertility maintenance conditions are met. The maximum fertilized area will be obtained at organic fertilizer using with minimal losses of the main plant nutrients: carbon (in the emissions' form of CO_2 and CH_4) and nitrogen (in the form of N_2O and NH_3). The dose of organic fertilizer is calculated based on one of the maximum present elements (nitrogen, phosphorus, potassium). The lack of the other two elements is compensated by the mineral fertilizers' introducing. The losses reducing overall costs is declining due to the mineral fertilizers' purchasing, storing, and using cost.

Results and Discussion

To perform an of ecological-and-economic assessment of various manure utilization systems example, information from regulatory documents and literature sources on the content of nutrients in the cattle and pigs original manure, nutrients losses at manure cleaning from premises by technical means, processing and storing it in various ways was used (Briukhanov, 2020; Briukhanov, 2016; Management, 2017) on the nutrients from the soil by biological harvest's removal.

An example of an ecological-and-economic assessment of manure utilization's problem possible solutions was made for three technologies of pigs' fattening at an enterprise with a capacity of 1000 pigs located in the Russian Central Federal district.

According to technology № 1, animals are kept on concrete floors at crushed straw substrate using. To clean the manure from the premises by a rod conveyor using. Manure in compost mixture-form is prepared for using at premises' cleaning. Bio-thermal compost maturation is conducted at field places. This organic fertilizer's application by spreading method is made. According to technology №2, the animals are kept on fully slotted floors above the baths for two weeks' manure collect and storage. This manure for use preparation is carried out by mechanical separation into fractions, its solid fraction's biothermal maturation – on field places is made, and liquid fraction in field storage is kept and in irrigation systems is used. The solid fraction is added after maturation-by spreading method. According to technology № 3, animals are kept during one year -as one fattening cycle, on warm, sawdust permanent bedding. After the manure unloading from the premises, it is stored as fertilizer on field places until it is used. The manure quarantining at the first two technologies is carried out on the enterprise's territory.

The calculation takes into account the methane and carbon dioxide emissions' amount in depending on the animals' housing technology, manure removal, process, storage and apply systems and it is presented in Table 2; the soils quality and crop rotation (unchanged for all technologies) and the applied mineral fertilizers' additional amount. The feed consumption, this bedding's amount and the room inside temperature to the technological regulations were corresponded.

Table 2. The carbon compounds' losses for three pig fattening technologies

Technology number	1	2	3
CH_4 fermentation emissions from all animals, t/year	1.5	1.5	1.5
CH_4–manure collection and storage losses, t	1.44	4.24	1.44
CH_4 – total emission's losses, t	2.94	5.74	2.94
CH_4 – methane emission, g / kg of gain	12.0	23.4	12.0
$CO_{2\_}$ CH_4 losses in equivalent-form, t	67.6	132.0	67.6
CO_2 – fossil emissions' energy using, t	184.06	203.13	156.06
CO_2 –feed storage emissions, t	0.173	0.173	0.173
CO_2 –mines fertilizers' production emissions, t	0.96	2.08	7.87
CO_2 – total emission, t	185.2	205.4	164.1
CO_2 –total emissions' equivalent, t	648.2	695.6	3083.0

Table 3. The manure output at pigs' fattening

Indicators	Technology number		
	1	2	3
Technological water into the manure channel flowing, l / head, per day	0	2.0	0
The compost material and bedding's annual consumption, t	530	0	530
Premises manure's annual output, t	2740	2910	2280

Table 4. Nitrogen loss at animals' housing, manure storage and fertilizer in soil application

Indicators	Technology number		
	1	2	3
N – produced taking into account the bedding, t	19.35	16.90	18.16
N – losses during manure disposal, t Including: NH_3 – losses , t; N_2O – losses, t	7.74 8.93 0.61	5.07 5.74 0.53	10.90 6.56 8.64
N – applied taking into account the losses, t N – the total losses after apply, t Including: in NH_3 – form, t; washed nitrogen in the NO_3 – form, t direct losses in the N_2O – form, t	11.61 4.06 2.38 1.96 0.23	11.83 7.10 4.31 3.55 0.23	7.26 2.54 1.49 1.23 0.14
N_2O- indirect losses at soil treatment and use	0.31	0.38	0.37
Fertilized area, ha	243	248	265
Fertilized area in relation to the total one, need for feed production, %	51	52	56
Nitrogen fertilizers (urea), etc applied in t,d,v	0.98	2.12	8.19
Nitrogen losses of mineral fertilizers, t,d,v Including: in NH_3 -form in NO_3^-form in N_2O-form	0.59 0.35 0.29 0.04	1.27 1.62 0.61 0.08	5.41 3.16 2.60 0.34
Received N with crop-and-root's residues, t	7.70	7.86	8.40
N – losses of N with crop-and-root's residues, t в том Including : in NO_3-form$^-$, in NH_3-form, in N_2O- form	2.69 1.30 1.57 0.20	2.75 1.32 1.62 0.15	2.94 1.42 1.72 0.17

Table 5. Indicators of greenhouse gases and ammonia's equivalent emissions

Type of losses	Technology №1	Technology №2	Technology №3
CO_2 emissions equivalent, kg/kg of gain	2.6	2.8	12.6
NH_3 emissions, g/kg of gain	53.9	54.2	52.7

Table 6. Technological losses of nitrogen due to three main operations of manure utilization

Name of the technological process	Technology number		
	1	2	3
Manure removal, processing and applying, including in the ammonia-form, g /kg of gain	31.6 30.0	20.7 19.3	44.5 22.0
Feed growing, including ammonia- form, g/kg of gain	29.7 14.4	45.8 29.0	45.0 21.3
Feed growing, including ammonia- form, kg/ha	30.0 14.5	44.9 30.4	41.6 19.7

The manure total output is determined from water standard entering into the manure channel and bedding material consumption's condition (Table 3).

Manure nitrogen losses at animal maintenance, fertilizers' storage and in soil application, are defined as 40, 30, and 60% for technologies 1, 2, and 3 respectively (Table 4) (Management, 2017).

Gas-form nitrogen's losses during manure disposal were estimated by two gases – ammonia and nitrous oxide. The nitrogen's rate converted into nitrous oxide is 0.02 kg/kg of nitrogen, released by animals.

According to the emissions equivalent indicators of PG and NH_3, taking into account emissions from non-renewable sources of energy, the best technology among three considered ones should be recognized as №1 (Table 5). It has greenhouse gas emissions in 8% lower in compared to technology №2 and it has almost the same ammonia emissions that is comparable to the other researchers' results (Ba et al., 2020; Briukhanov, 2019; Kammann et al., 2017; Samer 2016).

At the organic fertilizers' producing and use, nitrogen losses from liquid manure are lesser at the harvesting and preparation for using's stage. They are much larger for semi-liquid bedding free manure obtained due to № 2 technology, at its by plants and soil's assimilation stage (Table 6).

Thus, it can be argued that animals' maintenance technologies significantly affect the manure nitrogen losses on the main technological operations' distribution. The animals' maintenance technology under №1, it can be unconditionally recognized as the best due to the point of view of it ecological safety and organic fertilizer's efficiency using. Despite the almost identical nitrogen's losses (the most significant and expensive plants' element) during manure utilization for all pig fattening three technologies, the technology number 3 proved wasn't so competitive as to in terms of greenhouse gas emissions to the environment. The specific value of their CO_2 equivalent is in 4.8 times higher than that of technology №1 (Table 5). High values of greenhouse gas emissions are explained by large nitrous oxide emissions, with a high PGP, equal of 296.

So pig fattening technologies' complex ecological-and-economic assessment on fully slotted floors, with manure underground storage for two weeks and then its introduction after disinfection on the fields for grain crop rotation had proved itself as the best among the considered options. At the same time, the complex criterion has a value of 30.2 thousand rubles/ha. At animals keeping on concrete floors with bedding using, its indicator was 38.6 thousand rubles/ha, and on deep bedding – 42.4 thousand rubles/ha. Compost producing technologies they can be competitive only if the cost of moisture-absorbing materials' cost won't more than 15% of all technological operations performing cost.

Conclusions

The proposed methodology of ecological-and-economic assessment of manure utilization allows on the basis of complex criteria – minimum cost to make the necessary number of nutrients and organic matter per area's unit under the planned yield in compliance with the environment protection from pollution and soil fertility preserve's requirements for any type of livestock enterprise to justify a highly effective environment safe manure using system as raw material for organic fertilizers' producing. The of science-based manure disposal systems using will livestock enterprises' production efficiency increasing, significantly (at least in 3 times) of ammonia and greenhouse gases into the atmosphere emissions' reducing, as well as the damage from humus soils losses up to 700,0 thousand rubles per hectare. The assessment of manure disposal technologies by the proposed method using, will allow mistakes in design of new enterprises or existing ones reconstruction to avoid, and helps the environmental load on the environment to reduce.

Financing

Funding was provided by the Institute of livestock mechanization – a filial of the Federal state budgetary scientific institution Federal Agroengineering center VIM, Moscow, Russian Federation.

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Received: January 27, 2021; *Accepted:* June 30, 2021; *Published:* February, 2022