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ECOLOGICAL ASSESSMENT OF THE NITROGEN BUDGETS OF LIVESTOCK PRODUCTION SYSTEMS IN UKRAINE

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Змодельовано бюджет нітрогену на прикладі 5 типових тваринницьких господарств України різної спеціалізації. Показано відносне антропогенне навантаження різних тваринницьких господарств і ефективність використання поживних речовин у процесі виробництва продукції рослинництва і тваринництва. Визначено вхідні потоки нітрогену (N) — у складі кормів, добрив, насіння і посадкового матеріалу, біофіксації, атмосферних опадів, пожнивних решток рослин і вихідні потоки — у складі виробленої і реалізованої продукції рослинництва і тваринництва досліджених господарств. Встановлено, що у досліджених господарствах ефективність використання нітрогену (NUE_{farm}) становить 21,0–69,9%, тобто така кількість поживних речовин ґрунту та імпортованих кормів у нітрогенному еквіваленті депонувалася в реалізованій продукції, а решта N — у побічній продукції. Визначено співвідношення виробленої основної і побічної продукції в нітрогенному еквіваленті. Зокрема, у рослинництві на 1 т N пожнивних решток рослин отримують 1,06–1,11 т N зерна. В тваринництві на 1 т N виробленого гною отримують лише 0,15–0,78 т N основної продукції тварин. За рівнем виходу основної продукції відносно побічної, галузі тваринництва знаходяться у такому ранжованому порядку: скотарство — 0,15 т N молока і приросту живої маси на 1 т N виділеного гною; свинарство — 0,43 т N приросту живої маси на 1 т N гною і бройлерне виробництво — 0,78 т N приросту живої маси відповідно. Встановлено, що досліджені тваринницькі господарства спричиняють значне антропогенне навантаження на навколишнє природне середовище — інтенсивне навантаження на ґрунт (баланс від –30,2 до –42,2 кг N/га/рік) і високі показники викидів аміаку і парникових газів (NH_3, NO_x і N_2O) із систем зберігання і використання гною та сільськогосподарських угідь (16,3–1456,4 кг/га/рік). Встановлено, що на 1 т приросту живої маси телят у повітря викидається 132,4 кг NH_3, NO_x і N_2O; на 1 т виробленого молока корів — 7,6 кг; на 1 т приросту живої маси свиней (у середньому) — 30,3 кг; на 1 т приросту живої маси курей-бройлерів — 22,2 кг; на 1 т приросту живої маси і вовни овець — 53,7 кг NH_3, NO_x і N_2O.

Ключові слова: *тваринництво, побічна продукція, сполуки хімічно активного нітрогену, баланс нітрогену, ефективність використання нітрогену.*

INTRODUCTION

The livestock sector occupies an important place in the agrarian complex of the Ukrainian economy. Its development remains an important condition for food security, a stable socio-economic state of the state and a reserve for the export of agricultural products.

Previous studies of the state of nitrogen (N) use in agriculture have established a negative balance of nitrogen in crop production in Ukraine compared to EU countries, which can lead to irreversible losses of humus in agricultural soils. One of the reasons for the negative nitrogen balance in Ukraine is a significant reduction in the use of nitrogen as part of organic fertilizer. The accumulation of manure and the relative increase in the introduction of mineral fertilizers into the soil leads to environmental pollution due to the emission of reactive nitrogen (Nr) from manure management systems and agricultural land [1].

Also, the use of nitrogen for the livestock production in Ukraine has decreased due to the reduction of the cattle and pig population

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and the production of fodder for livestock [2].

For sustainable livestock production, agroecosystems need nutrients. Violation of the N balance of agroecosystems can lead to their irreversible destruction and pollution of the natural environment.

The gross N budget is a quantitative description of the main nitrogen flows in the natural environment or sectors of the economy within any geographical scale (at the level of the country, region or economy) during a certain period [3; 4].

The purpose of the research is to determine the balanceof N, efficiency of use N and loss of Nr in the gross N budget of different livestock production systems in Ukraine.

ANALYSIS OF LATEST RESEARCH AND PUBLICATIONS

Studies of the gross N budget of different livestock production systems are relevant in the world, because on these systems accounts for the majority of global losses of Nr. There are different livestock systems with significant differences in the use of forage, livestock and manure, and it is not yet well understood which factors influence the N balance and losses the most in each system [5–7].

Livestock production systems can broadly be classified in grassland based ruminant systems, mixed (crop-animal) and landless (industrial) systems. Grassland systems are completely terrestrial systems with less than one livestock unit per hectare. In mixed systems, a large part of the output value comes from activities other than livestock, while some of the animal feed is often imported. Industrial systems have a population of more than 10 head of livestock per hectare, and they depend mainly on external supply of feed, energy and other resources [8].

According to EU Directive 2010/75/EC «On industrial emissions (integrated pollution prevention and control)» in the countries of the European Union, farms with more than: 40,000 poultry, 2,000 pigs (with a live weight of more than 30 kg) or 750 sows are considered industrial ones. Farms of this capacity are equated with industrial enterprises due to their numerous ecological problems for the environment and human health [9; 10].

Livestock production systems convert plant protein to animal protein with an efficiency of 5–45%, and the remaining N (55–95%) is in urine and manure, causing its loss. The estimated global amount of manure N is 75–138 Tg N/year. Cattle (56–60%), sheep (12) and pigs (6%) have the largest share in manure N production. Approximately 40–50% of manure N is collected in cowsheds, pig houses, stables, paddocks, and only half of this amount is processed on arable land. Losses of gaseous N from manure are estimated at 45–75 Tg/year [11].

MATERIALS AND RESEARCH METHODS

Modeling of the nitrogen budget of livestock production systems was carried out according to generalized international approaches [12].

The basis for the research is typical livestock farms of Ukraine as of 2016: «Agroprime-Holding» LLC in Odesa Region, «Bakhmut Agrarian Union» LLC in Donetsk Region, «Kompleks Agromars» LLC in Kyiv Region, «Freedom Farm Bacon» LLC and «Borozenske» APC in Kherson Region.

The balance of nitrogen (N) in the soil-plant system was calculated for the cultivation of agricultural crops: winter and spring wheat, winter rye, winter and spring barley, corn for grain, spring oats, peas, sunflower, winter rapeseed, fodder root crops and melons.

To calculate the manure nitrogen production (N excretion) of cattle and pigs, the breed of farm animals was taken into account: large white, landrace, red white belt and red steppe dairy breed.

The emission of Nr in ammonia (NH_3), nitrogen oxides (NO_x) and nitrous oxide (N_2O) from manure management systems and agricultural land was calculated.

RESULTS AND THEIR DISCUSSION

According to the European classification [8], the researched livestock farms belong to

Table 1. **Characteristics of the researched livestock farms**

Name of the livestock farm	Type of livestock system	Specialization	Total number of animals, heads	Livestock per unit area, heads/100 ha/yr
«Borozenske» APC	crop-animal	dairy farming, pig farming	3464	30
«Agroprime Holding» LLC	crop-animal	sheep farming, pig farming	17655	79
«Freedom Farm Bacon» LLC	landless (industrial)	pig farming	20266	12588
«Bakhmut Agrarian Union» LLC	landless (industrial)	pig farming	86851	22466
«Complex Agromars» LLC	landless (industrial)	broiler chickens farming	32264719	363546

crop-animal and landless (industrial) livestock production systems. In Ukraine, cattle and sheep are farming in pasture and crop-livestock systems, and pigs and poultry are mainly farming in industrial landless systems (*Table 1*).

In crop-animal livestock systems («Agroprime-Holding» LLP and «Borozenske» APC), most of the N in the animal manure is ultimately returned to the land that produced the animal feed. In industrial livestock production systems («Freedom Farm Bacon» LLC, «Bakhmut Agrarian Union» LLC and «Complex Agromars» LLC), the manure is disposed of elsewhere, as the land-base is missing, and all animal feed is purchased (imported).

The manure utilization technologies used in the construction of the «Agroprime-Holding» LLC complex involve the processing of manure with its further use as organic fertilizer. The sewage treatment technology involves their separation into solid and liquid fractions, disinfection by anaerobic fermentation, purification of the liquid fraction to the state of technical water and solid biofuel (solid fuel pellets). The biogas released during the anaerobic fermentation of manure is sent to the boiler plant, which allows reducing the volume of energy consumption. Technical water is used for the needs of the pig complex and irrigation of fields.

In order to calculate the nitrogen budgets of livestock production systems the input flows of nitrogen from import fodder for livestock, fertilizers, seeds & planting material, biofixation, atmospheric deposition, crop residues and N output flows with agricultural crop & livestock sold products were determined (*Tables 2, 3*).

An important indicator that characterizes the efficiency of livestock production systems is the ratio of N outputs with the main and by-products (*Table 4*).

In crop production, 1.06–1.11 Mg N of grain is obtained for 1 Mg of N crop residues (straw, tops, stubble, roots). Crop residues are plowed up and used as bedding for animals.

In livestock, only 0.15–0.78 Mg N of the main products (milk, meat & wool) are obtained for 1 Mg of manure nitrogen production. According to the level of output of the main products relative to by-products, the livestock systems are in the following ranked order: cattle farming — 0.15 Mg N of milk and live weight gain per 1 Mg manure nitrogen production («Borozenske» APC); pig farming — 0.43 Mg N of live weight gainper 1 Mg N excreted («Agroprime-Holding» LLC, «Freedom Farm Bacon» LLC & «Bakhmut Agrarian Union» LLC) and broiler farming — 0.78 Mg N of live weight gain, respectivel («Complex Agromars» LLC).

The nitrogen balance in the soil-plant system reflects the level of load on the soil and the intensity of use of its nutrients (*Fig. 1*).

Table 2. **Nitrogen input flows from mineral & organic fertilizers, sowing and planting material, biofixation, atmospheric deposition, mineralization of crop residues and imports of fodder for livestock**

Name of the livestock farm	Input of nitrogen in the soil, Mg								Import N of fodder for livestock, Mg
	N input of mineral fertilizers	*N input of organic fertilizers	N input of seeds	Biological N fixation	Atmospheric N deposition	N input of crop residues	Total N input		
							Mg/yr	kg/ha/yr	
«Agroprime Holding» LLC	2180.3	20.5	41.2	163.1	78.7	375.5	2859.4	127.2	194.7
«Borozenske» APC	336.4	11.0	14.3	46.3	24.2	120.3	552.4	80.0	58.1
«Freedom Farm Bacon» LLC	–	–	–	–	–	–	–	–	585.5
«Bakhmut Agrarian Union» LLC	–	–	–	–	–	–	–	–	1402.6
«Complex Agromars» LLC	–	–	–	–	–	–	–	–	7358.7

Note: * Nitrogen excreted by animals in the previous year, taking into account the emission of N from the manure management systems and agricultural land.

Table 3. **N outputs with agricultural crop & livestock production**

Name of the livestock farm	N outputs with agricultural crop & livestock products, Mg					
	N output with grain		N output with milk, meat & wool		Total N outputs	
	produced	sold	produced	sold	produced	sold
«Agroprime Holding» LLC	2002.7	1831.1	108.3	103.2	2111.0	1934.3
«Borozenske» APC	392.0	314.0	17.8	18.8	386.6	332.8
«Freedom Farm Bacon» LLC	–	–	122.5	122.3	122.5	122.3
«Bakhmut Agrarian Union» LLC	–	–	415.8	415.6	415.8	415.6
«Complex Agromars» LLC	–	–	3228.8	3272.0	3228.8	3272.0

Table 4. **N outputs with crop residues & manure nitrogen production**

Name of the livestock farm	N outputs with by-products, Mg			The ratio of N outputs with the main products to N by-products	
	N crop residues	N excretion	Total outputs N	Crop production	Livestock
«Agroprime Holding» LLC	1805.4	260.5	2065.9	1.11:1	0.42:1
«Borozenske» APC	368.8	115.6	484.4	1.06:1	0.15:1
«Freedom Farm Bacon» LLC	–	275.4	275.4	–	0.44:1
«Bakhmut Agrarian Union» LLC	–	986.9	986.9	–	0.42:1
«Complex Agromars» LLC	–	–	–	–	0.78:1

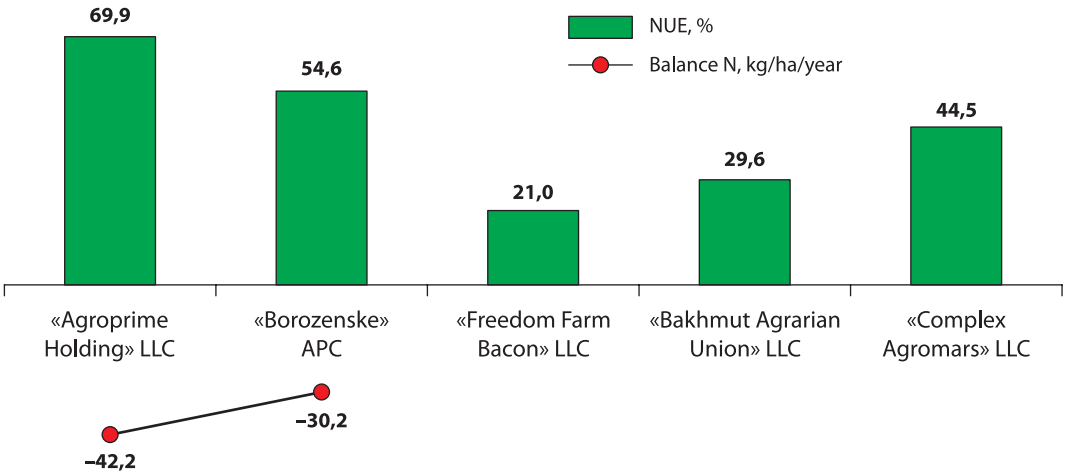

Fig. 1. Nitrogen utilization efficiency of the farm (NUE_{farm}) and nitrogen balance in the soil-plant system

The nitrogen balance in the soil-plant system is the difference between the input flows of N in the soil and the output flows of N with the crop production, taking into account the emission of Nr from agricultural lands.

The crop-animal livestock systems («Agroprime-Holding» LLC and «Borozenske» APC) have a negative nitrogen balance in crop production from –30.2 to –42.2 kg N/ha/year, this means that much more nutrients are removed from the soil than are received there.

The NUE_{farm} reflects the efficiency of the use N of soil and imported fodder with the sold crop and livestock production, taking into account the emission of Nr from agricultural land.

It was established that the NUE_{farm} is 21.0–69.9% on the investigated farms, i.e., such amount of soil nutrients and imported feed in nitrogen equivalent was deposited in the sold products, and the rest of N was depositedin by-products (crop residues & manure). Thus, the higher the farm's NUE, the more efficient the production, but it is necessary to take into account the livestock production systems. In crop-animal livestock production systems (Agroprime Holding LLC and Borozenske APC) the NUE is higher (on average —62.3%)compared to landless industrial systems (Freedom Farm Bacon LLC, «Bakhmut Agrarian Union» LLC, «Agromars» LLC) (NUE on average —31.7%) due to the sale of agricultural crops.

Among landless industrial systems, the broiler chickens farming has a higher NUE — 44.5% than the pig farming — 25.3%, which is related to the different physiological ability of broiler chickens and pigs to transform the nutrients of the ration into meat products.

Manure without special treatment is a source of NH_3 emissions due to ammonification, which is why, taking into account the current volumes of animal food production in the world, the livestock sector is considered the main source of NH_3 emissions in the agricultural sector [8].

Fig. 2 shows the level of anthropogenic load on the natural environment from the activities of the livestock production systems as a result of Nr emissions from manure management systems and agricultural land.

In mixed livestock systems («Agroprime-Holding» LLP and «Borozenske» APC), the indicated quantitative losses of Nr from agricultural sources must be taken into account when planning the application of mineral and organic fertilizers and plowing plant residues into the soil with the aim of balanced use of nutrients in the soil-plant system.

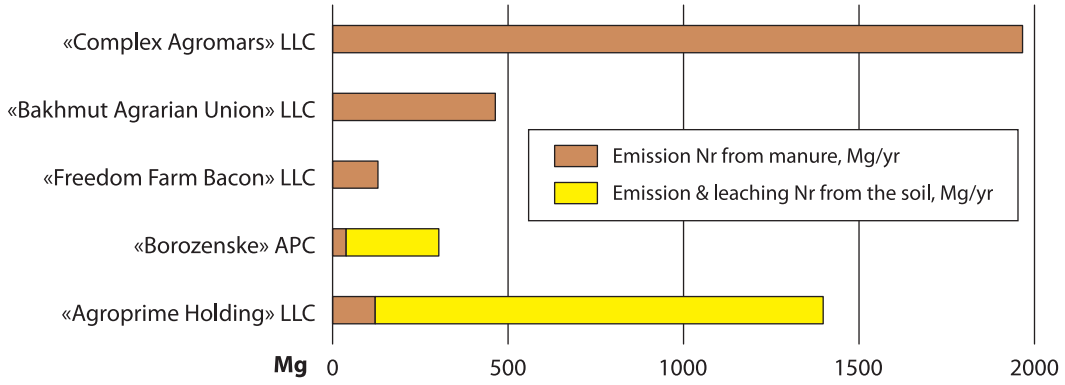

Fig. 2. Emission and leaching of Nr from manure management systems and agricultural lands

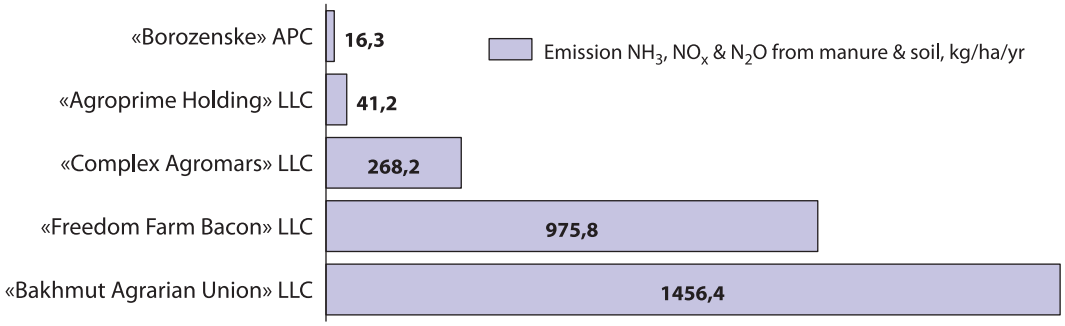

Fig. 3. Emission of NH_3, NO_x and N_2O from manure management systems and agricultural land per 1 ha of land area

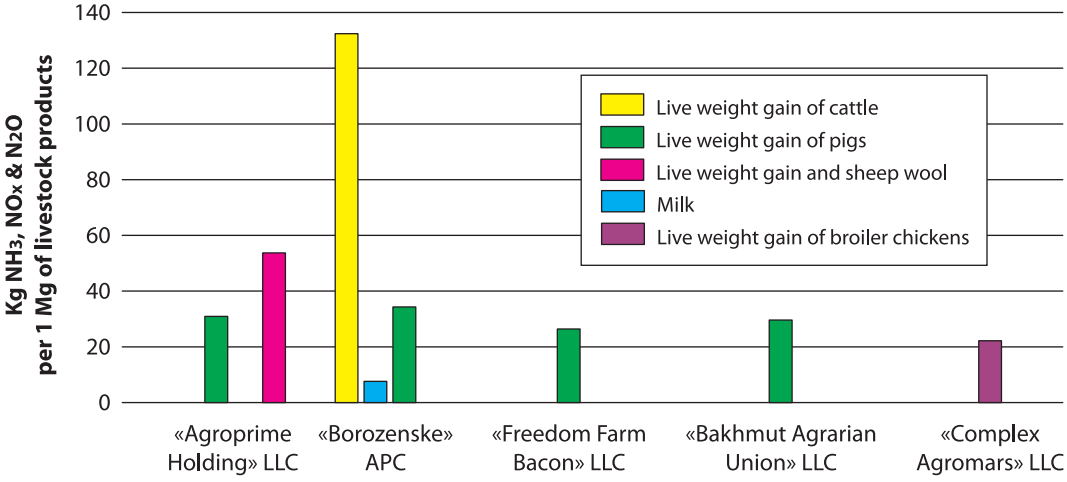

Fig. 4. Emission of NH_3, NO_x and N_2O from manure management systems per 1 Mg of livestock products

It is obvious that the largest local air pollution is caused by large poultry and pig farms («Bakhmut Agrarian Union», «Freedom Farm Bacon» LLC and «Complex Agromars» LLC), which have the highest density of livestock per unit area of agricultural land (*Fig. 3*).

The share of greenhouse gas — N_2O in the total emissions from agricultural land is 76–85%, and in the total emissions from manure management systems of the studied farms — within 5%.

It was established that 132.4 kg of NH_3, NO_x and N_2O are emissed for 1 Mg of live weight gain of calves; 7.6 kg of NH_3, NO_x and N_2O per 1 Mg of produced cow's milk; 30.3 kg of NH_3, NO_x and N_2O per 1 Mg of live weight gain of pigs (on average); 22.2 kg of NH_3, NO_x and N_2O per 1 Mg of live weight gain of broiler chickens; 53.7 kg of NH_3, NO_x and N_2O per 1 Mg of produced live weight and wool of sheep (*Fig. 4*).

CONCLUSIONS

1. The obtained results show the expediency of modeling the nitrogen budget of livestock production systems in Ukraine for the comparative assessment of their anthropogenic load and the efficiency of nutrient use.

2. The main factors affecting the balance of N, NUE_{farm} and Nr loss in livestock systems are specialization of the farm; the level of application of organic and mineral fertilizers into the soil in relation to the yield of crops; the level of reproduction and productivity of animals per unit of feed consumption; available by-product management systems and volumes of product sales (exports).

3. The livestock production systems cause a significant anthropogenic load on the natural environment — intensive soil load (average –30.2 to –42.2 kg N/ha/year) and high rates of NH3 and greenhouse gas emissions from manure management systems and agricultural land (16.3–1456.4 kg/ha/year).

4. The determined indicators of the N balance in the soil-plant system, NUE_{farm} and Nr loss in combination with other agroecological indicators should be used to assess the effectiveness of the implementation of measures to improve technology at the enterprise in order to increase the efficiency of the use of nutrients and reduce the anthropogenic load on the natural environment.

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