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ORIGINAL ARTICLE

Environmental pollution caused by the manure storage

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The purpose of this work was to compare the quality indicators of manure with different ways of its removal and storage for pollution of the environment. The research was carried out at three farms with different variants of removal, storage and processing of manure: using deep, unchangeable for a long time straw litter, processing of manure in a bioreactor-fermenter and sedimentation in open-air lagoons. By the amount of NPK content per 1 kg of fertilizer, the highest rates were observed for the deposition on the deep litter – 7.69 g. The least of these elements was in the fertilizer obtained as a result of storage in the lagoon – 6.16 g. At the variant of manure processing in the bioreactor-fermenter intermediate indicators – 6.69 g were observed. The highest manure moisture index was for storage in the lagoon – 17.71% and 1.38% more compared with the option on deep litter and bioreactor-fermenter. The lowest amount of weed seeds was deposited on deep litter – 79 units/ml, which is 24 and 38 units/ml more than for processing in a bioreactor-fermenter and storage in the lagoon. The indicator of germination of weeds, which is very important in terms of the future use of manure in organic fertilizers, in general, for all variants of storage (processing) had positive indicators. The germination index of weeds under storage on deep litter was 5.72%, which is 3.14 and 4.42% less than by processing in a bioreactor-fermenter and in a lagoon. The largest emissions of N_2O (nitrogen oxide) were 40712.45 kg at manure storage in the lagoon, which is 39781.88 kg more than at the variants of deep-litter storage and bioreactor-fermenter.

Key words: Deep litter; Bioreactor-fermenter; Lagoon; Qualitative and sanitary indices; Organic fertilizer

Introduction

The use of organic fertilizers is one of the most powerful and fastest factors in increasing soil fertility and yields of all agriculture crops. By improving the nutrition conditions of plants with the help of fertilizers, it is possible to increase the growth of plants, accelerate the pace of their development and significantly increase the yield. In addition, organic fertilizers have a significant effect on the quality of the crop, increasing the amount of protein, sugar, and starch in it, and increasing the resistance of plants to adverse environmental conditions/diseases and giving the possibility to get environmentally safe raw materials and products (Zhong et al., 2010). The summary effect thanks to the introduction of tons of manure is, in terms of grain, 1.2 c/ha of additional products. In this regard, the implementation of measures to increase the accumulation of organic fertilizers should be one of the main objectives of livestock farms under modern economic conditions. Manure production at dairy cattle farms should be considered as the production of the second (after milk) products (Ruban et al., 2017).

Each individual bovine animal may give at least 9 tons of manure per year. In order to get high-quality organic fertilizer, manure must be properly stored: in special manure reservoirs, compacted clamps on the field, in lagoons. The storage time should not exceed 4–5 months, and the manure should acquire the half-immature state (Tien et al., 2017).

Recently, modern farms have used manure processing systems for biogas, compost, sedimentation, closed and open lagoons (Anon et al., 2007; Wang et al., 2012). As practice shows at many milk farms, the greatest attention is paid to the timely removal of manure to ensure normal microclimate and the cleanliness of the premises, and the issues of ecology and manure production, as fertilizers, are ignored (Bomko et al., 2018; Faly & Brygadyrenko, 2018; Borshch et al., 2019; 2020; Roman et al., 2020; Grymak et al., 2020; Mazur et al., 2020). At the same time, the system of litter bringing in and removal of manure in dairy farms and complexes should provide optimum conditions for keeping animals, maintenance of good sanitary conditions in the premises, rational use of manure as organic fertilizers, protection of the environment from pollution and it must be inexpensive (Toumi et al., 2017). To the greatest extent these requirements correspond to the free-stall housing of cows and replacement heifers on deep, unchangeable for a long time straw litter, at such method of maintenance the animal excrements are allocated on the floor of the room – practically directly in the manure reservoir. The working processes consist of the removal and taking out of manure one – twice a year. However, this requires large straw consumption. The average gross index of straw collection in recent years in Ukraine constituted 85238 tons. At the same time, the percentage of use for litter is 6.2%. One ton of cereal crops straw contains 5 kg of nitrogen, 2.5 kg of phosphorus and 6 kg of potassium (Borshch et al., 2017a; Borshch et al., 2017b; Ruban et al., 2020).

The average annual yield of half-rotten manure from deep litter is 4–6 tons per 1 cow. The composition of manure includes 25–35% straw and 65–75% of excrements. By the period of cleaning, this manure becomes semi-rotten. Relative humidity of manure is 74–77% and depends on the expenditure of litter and the time of cleaning the cow house. The volume of manure mass in cow houses

with deep litter in the undisturbed structure of the manure layer is within the range of 0,95–0,98 t/m^3, the bulk weight – 0.5–0.72 t/m^3 (Janzen et al., 1999). At the moment it has been established that one third of anthropogenic pollution of the earth's atmosphere is caused by the production of agricultural products (Hoffmann et al., 2007). Animal agriculture belongs to its main pollutants. According to the FAO prediction, the future situation may worsen as the demand for animal protein is increasing in the world. Today, livestock production gives for 9% of the world's emissions of the most common greenhouse gas (carbon dioxide, 65% nitrous oxide, most of which is present in manure, 37% of all anthropogenic methane and 64% ammonia) (Coats et al., 2011; Resende et al., 2014; Stowe et al., 2015).
Among the proposals for the protection of the environment under the production of milk, an important role is assigned to the improving of the maintenance technology for animals – this is one of the few constructive possibilities to reduce pollution without radical measures related to the refusal of the production of these products. In this regard, in most developed countries, technologies with better environmental performance are being implemented (Cao & Harris, 2010; Walsh et al., 2012; Barret et al., 2013).
The purpose of our work was to evaluate the effect of manure removal and storage patterns on the environment.

Materials and Methods

The research was carried out in central part of Ukraine (Kiev region) at three farms with different variants of removal, storage and processing of manure: using deep straw litter (manure removal takes place three times per year), processing of manure in a bioreactor-fermenter and sedimentation in open-air lagoons (Figure 1). All farms hold Holstein breed cows with an average annual livestock of 400 cows. Manure analyzes (waste recycling) were sampled a day before they were exported to the field. Sampling took place in August 2019. The average daily temperature was + 21.3°C, and precipitation was 51 mm.

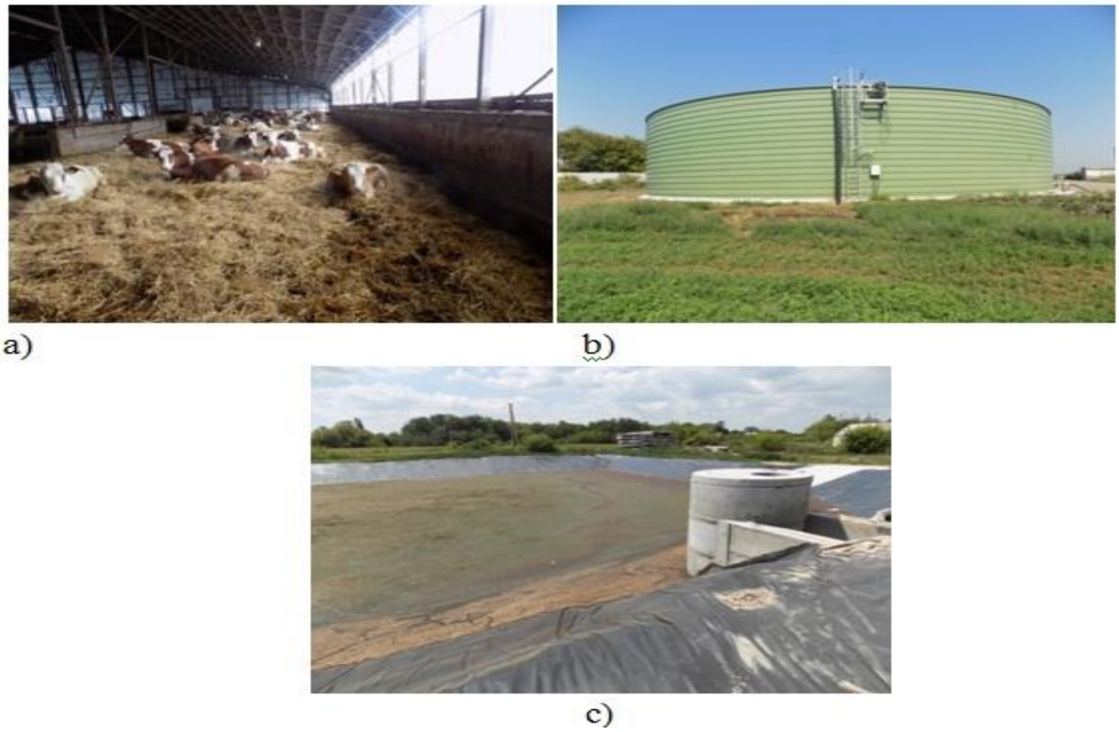

Figure 1. Manure storage and processing methods: a) deep litter; b) a bioreactor-fermenter; c) open-air lagoon.

Humidity of raw materials was determined by the generally accepted method. From a sample of 1 liters of manure after mixing, a sample of mass from 40 g to 60 g was taken and placed into aluminum weighing bottles, pre-dried and weighed on laboratory weights. The manure was dried in a thermostat at a temperature of 100–105°C for 6–10 hours to constant weight. After cooling, the weighing bottles were weighed. The presence of extraneous inclusions was determined by sampling with the weight of 1 kg each in three reservoir locations. Third-party inclusions (stones, metal objects, etc.) from these samples were picked out and weighed.The content of organic matter was determined by the method of ash content determination. The dried sample, with mass of 5.0–10.0 g, was placed into crucibles, placed in a muffle furnace and heated to the appearance of smoke. The duration of burning, which depends on the chemical composition of manure, ranged from 5 to 6 hours. The light gray color of ash and the absence of coal particles indicate the complete ashing of the material. After the ashing, the crucibles were cooled during 10–15 minutes in a muffle furnace, and then 30–40 minutes in a desiccator, after that they were weighed.
The nitrogen content was determined by the Kjeldahl method. The method is based on the mineralization of the raw material during heating with concentrated sulfuric acid at the presence of hydrogen peroxide, a mixed catalyst or a solution of phenol in sulfuric acid, with the following distillation of ammonia in a solution of boric acid and titration with sulfuric acid. The phosphorus content was determined by photometric method based on the mineralization of dry organic matter during heating with concentrated sulfuric acid at the presence of hydrogen peroxide, with the following determination of the optical density of the painted phosphor molybdenum complex, restored to the molybdenum blue. The content of potassium was determined by the fire-photometric method. The method is based on the mineralization of dry organic matter during heating with concentrated sulfuric acid in the presence of hydrogen peroxide or a mixed catalyst with the subsequent determination of total potassium.
The presence and germination of weeds was determined as follows. A sample with the mass of 1 kg was washed through a clean sieve and all the seeds of weeds were taken out from the sieve. From the obtained seeds, 100 whole grains were taken, placed into Petri dishes, and placed into the thermostat. For seed germination, white paper was used, which was moisturized before seeding.

The seeds were spread evenly at a distance of 0.5–1.5 cm, covered the sprouts with glass plates. The seed germination period was 10 days at a temperature of 20°C. Manure temperature was determined by direct measurement at a depth of 40–45 cm using the thermometer A36PF-D43 (USA).

Emissions of N_2O (nitric oxide) and N as a result of cleaning, storage and use of manure and loss of N as a result of evaporation were determined according to generally accepted methods (Anon et al., 2001).

Emissions of nitric oxide (N_2O) as a result of cleaning, storage and processing of manure were determined by the formula:

$$N_2O = [((N \cdot Nex \cdot MS) \cdot EF_3))] \cdot \frac{44}{28}$$

where, N_2O – emissions of nitric oxide as a result of cleaning, storage and processing of manure, kg N_2O/year; N – number of cows at the farm, heads; Nex – average nitrogen concentration per head, kg/head/year; MS is the proportion of annual nitrogen emissions produced within a certain system of cleaning, storage and processing of manure (2 for deep litter, 0 for a bioreactor-fermenter, and 17.5 for open-type lagoons); EF_3 – emission coefficient for direct N_2O emissions from manure cleaning, storage and processing system, kg N_2O-N / kg N (0.01 for deep litter, 0.002 for bioreactor-fermenter, 0.005 for open-type lagoon); 44/28 – conversion factor of N_2O-N emissions into N_2O emissions.

The average nitrogen allocation (Nex) was determined by the formula:

$$Nex = Nrate \cdot \frac{TAM}{1000} \cdot 365$$

where Nex – annual nitrogen allocation kg/head/year; Nrate – rate of nitrogen emission, kg N/1000 kg live weight/day (for Eastern European countries it constitutes 0.35); TAM – typical mass of cows, kg (for Holstein breed it constitutes 580 kg).

Emissions of nitric oxide as a result of evaporation (N_2O vaporization) were determined by the formula:

$$N_2O_{vaporization} = (N_{vaporization} \cdot EF_4) \cdot \frac{44}{28}$$

where N_2O vaporization – indirect emissions of N_2O associated with the evaporation of NH_3 nitrogen as a result of cleaning and storage of manure, kg N_2O/year; EF_4 – is emission factor for N_2O emissions in the result of nitrogen deposition, kg N_2O-N/kg N (it constitutes 0.20 for all manure storage options).

Loss of nitrogen as a result of washing out ($N_{washing\ out}$) from the system of cleaning, storage and processing of manure was determined by the formula:

$$N_{washing\ out} = (N \cdot Nex \cdot MS) \cdot (\frac{Frac_{washing\ out}}{100})$$

where $N_{washing\ out}$ is the amount of nitrogen that is washed out of the system, kg / year; $Frac_{washing\ out}$ is the percentage of nitrogen loss from manure as a result of washing out at solid and liquid storage of manure, % (it constitutes 10% for all manure storage options).

Loss of nitrogen as a result of evaporation ($N_{evaporation}$) was determined by the formula:

$$N_{evaporation} = (N \cdot Nex \cdot MS) \cdot (\frac{Frac_{evaporation}}{100})$$

where $Frac_{evaporation}$ is the percentage of nitrogen that evaporates in the form of NH_3 as a result of cleaning and storage of manure, % (20% for deep litter, 35% for bioreactor-fermentor, and 40% for open-type lagoon).

The data were statistically processed using STATISTICA v. 11.0 software. The Student's *t*-test was implemented to estimate the statistical significance of the obtained values. Data were considered significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$.

Results and Discussion

The most important elements contained in organic fertilizers are NPK and their compounds. By the amount of NPK content in 1 kg of fertilizer, the highest rates were observed with the variant of maintenance on the deep litter – 7.69 g. The least of these elements were in the fertilizer obtained as a result of storage in the lagoon – 6.16 g. According to the method of manure processing in a bioreactor-fermenter they observed intermediate indicators – 6.69 g (Table 1).

Table 1. NPK content in organic fertilizers, depending on the variants of removal, storage and processing of manure, g/kg.

Element	Manure storage method (n = 10)		
	Deep litter	Bioreactor-fermenter	Laguna
Nitrogen	3.16 ± 0.08	2.84 ± 0.09*	2.63 ± 0.08***
Phosphorus	2.34 ± 0.09	2.01 ± 0.06**	1.87 ± 0.06***
Potassium	2.19 ± 0.15	1.84 ± 0.14	1.66 ± 0.07**

Note: as compared with deep litter material *P<0.05; **P<0.01;***P<0.001.

It was found that the highest manure moisture index was under storage in the lagoon – 17.71% and 1.38% more compared with the variant on deep litter and in the bioreactor-fermenter (Table 2). The mass fraction of organic matter of manure was the highest at maintenance on the deep litter –81.72%, which is 4.44 and 7.66% higher than the technologies with the use of the bioreactor-fermenter and lagoon, respectively. The same situation was observed according to the content of the most essential for preventing the degradation (erosion) of soils' macro-elements – nitrogen, phosphorus and potassium. The method ofmanure processing in the bioreactor-fermenter showed the lowest indicator of foreign inclusions – 0.014%, that is 0.013 and 0.008% less than at processing in deep litter and in the lagoon. The smallest amount of weed seeds was deposited on deep litter – 79 units/ml that is 24 and 38 units/ml more than at processing in a bioreactor-fermenter in the lagoon. This can be explained by the fact that in the process of fermentation in deep litter, which lasts for 3.5 months (110 days), part of the weeds and straw seeds rots and decomposes. The indicator of weeds germination, which is very important from the point of view of the future use of manure as a fertilizer, was slightly lower than maintenance on deep litter – 5.72%, under processing in the bioreactor-fermenter this indicator was 8.86%, and in the lagoon – 10.14%. The manure storage temperature in the lagoon was lower by 10.50 and 1.76%, compared with maintenance on deep litter and in a bioreactor-fermenter.

Table 2. Indicators of manure quality depending on the way of storage.

Indicator	Method of storage (processing) of manure (n = 10)		
	Deeplitter	Bioreactor-fermenter	Laguna
Humidity,%	75.54 ± 1.37	93.87 ± 1.86***	95.25 ± 2.08***
The mass fraction of organic matter,%	81.72 ± 2.81	77.28 ± 2.53	74.06 ± 2.64
Presence of extraneous inclusions,%	0.027 ± 0.0084	0.014 ± 0.0036	0.022 ± 0.059
Presence of weed seeds, pc/ml	84 ± 2.83	103 ± 3.18***	107 ± 3.53***
Germination of weed seeds, %	5.72 ± 0.73	8.86 ± 1.16*	10.14 ± 1.36*
Temperature, °C	44.07 ± 0.94	42.31 ± 0.46	38,57 ± 0.59***

Note: as compared with deep litter material *P<0.05; ***P<0.001.

Intensification of agriculture in general and breeding in particular is a factor of the emissions increase of carbon dioxide, methane, ammonia, nitrogen oxide, volatile substances and other gases into the atmosphere, which in turn destroys the ozone layer and has an impact on the global processes of climate change in the world. American scientists have found that one cow enterally and in the form of excrement, allocates from 250 to 500 liters of methane daily. This process depends not only on the structure of the diet and the concentration in it of concentrated and succulent feeds, but also on the technology of keeping animals and ways of removing, storing and exploiting manure at farms (Coats et al., 2016; Coats et al., 2016).

The largest emissions of N_2O, which is an ozone-depleting substance, as well as greenhouse gas, were 40712.45 kg for manure storage in an open lagoon (Table 3). Under the storage in deep litter and in a bioreactor-fermenter, this figure was 930.57 kg. The same situation was observed with the loss of N_2O due to evaporation – 56997.43 kg under the storage in an open lagoon, against 3722.28 kg and 3256.99 kg under the storage in deep litter and in a bioreactor-fermenter, respectively.

Table 3. Influence of manure storage method on environmental pollution.

Indicator	Manure storage method (n=400)		
	Deep litter	Bioreactor-fermenter	Laguna
Emissions of N_2O from cleaning, storage and processing of manure, kg/year	930.57	930.57	40712.45
Emissions of N_2O from evaporation, kg/year	3722.28	3256.99	56997.43
N losses from cleaning, storage and processing of manure, kg/year	5927.20	2963.60	51863.01
Losses from evaporation, kg/year	11854.40	10372.60	181520.50

N losses, which, due to high concentrations in the air, can cause breathing in animals, were also the highest under manure storage in the lagoon – 51,863,01 kg as a result of cleaning, storage and processing of manure and 18,1520,50 kg as a result of evaporation. Significantly higher emissions of N_2O and N at manure storage in an open-air lagoon are explained with significantly higher values of the annual allocation of N and coefficient of N_2O emission compared to storage in deep litter and in an anaerobic bioreactor-fermenter.

Conclusion

We established that the method of removal, storage and processing of manure had strong impact on organic fertilizers quality, amount of N_2O emissions and N losses. Manure qualitative and sanitary parameters were better for method of removal and storage on deep straw litter than for processing in closed bioreactor-fermenter and lagoon. We registered the lowest N_2O emissions and N losses for manure processing in a bioreactor-fermenter. In this case, the content of NPK and organic matter of fertilizer obtained from deep litter exceeds the analogue indicators of other storage methods due to the daily introduction of straw. In addition, such a system of the removal, storage and processing of manure requires considerably lower capital costs, compared with processing in a bioreactor-fermenter and storage in lagoons.

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