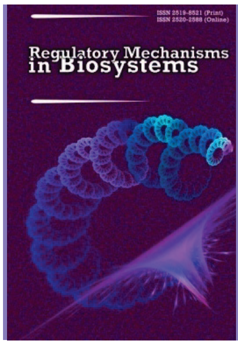

Regulatory Mechanisms in Biosystems

ISSN 2519-8521 (Print)
ISSN 2520-2588 (Online)
Regul. Mech. Biosyst.,
2024, 15(1), 183–187
doi: 10.15421/022427

Methods of assessing emissions of contaminants from sties into the air

O. V. Boiko*, M. S. Nebylytsja*, O. F. Honchar*, T. G. Osokina*, Y. V. Lesyk**, B. V. Gutyj***

**Cherkassy Experimental Station of Bioresources National Academy of Agricultural Sciences of Ukraine, Cherkassy, Ukraine*
***Institute of Animal Biology of NAAS, Lviv, Ukraine*
****Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies Lviv, Ukraine*

Article info

Received 30.12.2023
Received in revised form 02.02.2024
Accepted 18.02.2024

Cherkassy Experimental Station of Bioresources National Academy of Agricultural Sciences of Ukraine, Pasterivska st., 76, Cherkassy, 18036, Ukraine. Tel.: +38-047-231-40-52. E-mail: bioresurs.ck@ukr.net

Institute of Animal Biology of NAAS, V. Stus st., 38, Lviv, 79034, Ukraine. Tel.: +38-068-503-46-25. E-mail: yaroslav_lesyk@inenbiol.com.ua

Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies Lviv, Pekarska st., 50, Lviv, 79010, Ukraine. Tel.: +38-068-136-20-54. E-mail: bvh@ukr.net

Boiko, O. V., Nebylytsja, M. S., Honchar, O. F., Osokina, T. G., Lesyk, Y. V., Gutyj, B. V. (2024). Methods of assessing emissions of contaminants from sties into the air. Regulatory Mechanisms in Biosystems, 15(1), 183–187. doi:10.15421/022427

Provision of competitiveness in the sphere of animal farming in Ukraine requires the introduction of innovative systems of technological support involving modern microprocessor control-measurement systems and devices. The method of continuous automatic record of emissions of contaminants from animal premises reveals patterns in emissions of the main air contaminants and allows their mass concentrations and dynamics of emissions to be tracked over 24 h period. By employing this method, we determined the coefficients of 24 h emissions of carbon dioxide and methane from premises for fattening young swine. The coefficients of 24 h emission of ammonia were found to be significantly lower in the sty with a slatted floor in pens for the winter, spring, and autumn periods compared with the sties with concrete floor. However, coefficients of 24 h emission of methane were significantly higher by 76.1–286.9% in the sty with a slatted floor, which is associated with the peculiarities of technology of the self-cleaning system. Two-times removal of manure from the sty with concrete floor significantly reduced the average annual coefficients of emission of carbon dioxide, ammonia, and methane, by 12.1%, 22.4%, and 13.5%, respectively. Analysis of emission of the main contaminants from the sties with slatted and concrete floor in pens indicated a significant effect of this factor on the amount of emission, structure, and presence of seasonal and daily variability in those parameters. Accumulation of experimental materials regarding emission of contaminants will allow average actual parameters of emissions from small pig farms to be identified, which will allow adequate assessment of the effect their activity has on the environment, particularly in residential areas, and substantiate the minimal allowable distances to sanitary-protective zones.

Keywords: carbon dioxide; ammonia; methane; manure; swine; small pig farms; sanitary-protective zone.

Introduction

Animal farming accounts for 38% of the total agricultural production. Its main spheres are cattle, pig, sheep, and poultry farming. Its main objective is producing high-quality food products and valuable raw material for the food and light industries. According to the data (Zhukorskyi et al., 2014), the largest amount of emissions in Ukraine (chemical contaminants (without greenhouse gases), microorganisms, dust) have been caused by poultry farming – 72%, pig farming – 19%, and other spheres – 9%. Animal farms contaminate the air with such categories of pollutants as ammonia, hydrogen sulfide, methane, alcohols (methanol, ethanol, etc.), phenols, complex ethers, carbonate compounds (aldehydes and ketones), carbonate acids, sulfides, and disulfides, mercaptans, amines, and carbon dioxide. Those compounds, according to reports, have malodorous effect, which manifests by strong unpleasant odor (Chemela et al., 2012). Furthermore, according to research, people exposed to those compounds can suffer headache, muscle tension, pain in the limbs, and irritation of the mucous membranes of the eyes and airways (Schiffman & Williams, 2005). The strongest malodorous air contaminants are hydrogen sulfide and sulfur compounds (mercaptans, thyophenols, and thyoethers with much more intensive odor than hydrogen sulfide), and also ammonia.

In addition, the literature data (Nebylytsia & Boiko, 2019) suggest that provision of competitiveness in the sphere of animal husbandry of Ukraine requires introduction of innovative systems of technological supply by introducing modern microprocessor control-measuring systems and devices. Currently, there is a problem of controlling air pollution with methane (identified to danger class 4 – low-dangerous) from animal premises (Bardov et al., 2020). It exerts low narcotic effect and depends on greenhouse gases, whereas the market offers no cheap devices and sensors. To solve this issue, Swedish researchers of Linköping University have developed a calibration method using a cheap thermocatalytic methane sensor that can measure currents of this gas against the background of very low volumetric concentrations (Bastviken et al., 2020).

It has to be noted that so far, mass concentrations of hazardous contaminant such as fractions of suspended compounds $PM_{2.5}$ and PM_{10} have not been monitored on animal farms of Ukraine. This air contaminant includes both solid microparticles and small droplets of fluids, measuring 10 to 1.0 and 2.5 µm; the other indication and name of the particles is FSP (fine suspended particles, fine particulate matter, small-dispersed weighed particles, thin-disperse dust).

Therefore, researchers of the Cherkasy Research Station of Bioresources of the National Academy of Agrarian Sciences of Ukraine developed a modern measuring-quantifying complex Electronic Mono-Block Analyzer of Air Environment VOK APSE-M to measure over ten parameters, in particular small particles of suspended dust fractions of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} and low volumetric concentrations of the polluting gases CO_2, NH_3, H_2S, and CH_4 by continuous automatic record (Nebylytsia & Boiko, 2022). As of now, there are some methods (Phillips et al., 1998; Insausti et al., 2020; Cardador et al., 2022) to identify amounts of air contaminants. Comparing calculation and instrumental methods of identifying emissions of contaminants into the air is relevant and has theoretic and practical values. The objective of our study was comparing calculation and instrumental methods of air-contamination assessment in the conditions of small objects of animal farming in Cherkasy Oblast with some technological specifics.

Materials and methods

The experimental studies were carried out adhering to the requirements of the Law of Ukraine No. 3447-IV as of2/21/2006 On Protection of Animals From Abuse, according to the main principles of the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (Strasbourg, 1986), the Declaration on Humane Treatment of Animals (Helsinki, 2000), and the General Ethical Principles of Conducting Experiments on Animals adopted by the First National Congress of Bioethics (Kyiv, 2001).

The research was conducted in Cherkasy Oblast according to the provided scheme, in brick premises equipped with a supply-exhaust ventilation system with a mechanical damper, on the farms of Cherkasy State Agricultural Research Station: the National Scientific Center the Institute of Land Farming of the National Academy of Agrarian Sciences (Red-White-Striped swine were kept on a solid concrete floor with one- and two-times manure removal), Zolotonivskyi Bekon Ltd. (swine of the meat genotypes Yorkshire, Landrace, and Petiene of French origin, kept on a slatted floor with self-cleaning system of manure removal).

Table 1
Scheme of the experiment

Parameters	Seasons: winter, spring, summer, autumn
Measuring microclimate parameters	temperature, relative humidity
Measuring emission of contaminants and compounds	CO_2, NH_3, CH_4, $PM_{1\text{-}10}$
Type of floor and regularity of manure removal per day	slated and concrete with one- and two-times removal

The methods of measuring emissions of contaminating gases were as follows: mass concentration of gasses in the air was identified using a VOK APSE-M (Fig. 1a) by the method (Bashchenko et al., 2021) of continuous automatic record. Measurement was conducted using the following algorithm – one measurement after 3 s for 2 min, which equaled forty measurements. The next stage was identifying the mean arithmetic value of the forty measurements, and recording it on the memory of the microprocessor, after which there was a four-minute pause. Therefore, the general interval equaled one measurement each six-minute interval throughout monitoring. Contaminated air in the premises was sampled under air exhausters, and outside, at the distance of about 1 m from the air-intake canal. Elevating tripods were used to set the devices at 210 cm above the floor inside and 170 cm above ground outside (in a wooden instrument shelter) (Fig. 1b, 1c).

a *b* *c*

Fig. 1. Sampling contaminated air using the modern measuring-calculation complex VOK APSE-M: *a* – general appearance of VOK APSE-M (comprised of three portable internal mono-block devices and one external one, located in the instrument shelter); *b* – method of continuous sampling of contaminated air with VOK APSE-M in the sty under exhaust ventilator; *c* – method of continuous air sampling using VOK APSE-M outside the sty at 1 m distance from air-collecting canal

Ventilation rates were measured using an electronic wing-wheel anemometer. To calibrate the sensors measuring CO_2, NH_3, and CH_4, we used certified calibrating gas mixtures (No. 100-44/21, 1121-44/21, and 99-44/21) in 2 L high-pressure gas cylinders, manufactured by the State Enterprise Ukrmetrteststandart, and also a UTR-1 valve with a manometer. Gas emissions (E), expressed in mg/h, were estimated on an hourly basis according to Filippe et al. (Bashchenko et al., 2009) using the following formula: $E = D \times (C_{in} - C_{out})$, where: D is mass loss of air per hour (kg/h); and C_{in} and C_{out} are concentrations of contaminating gas in premises and outdoors, respectively (mg/kg of air).

Hour emissions were converted into daily coefficients of emission in g/animals, live mass of 100 kg. The obtained daily coefficients were compared to the estimates and the literature data.

The obtained data was analyzed through Statistica 6.0 software (StatSoft Inc., USA). The data in the tables are presented as x ± SD (mean ± standard deviation). Differences between the values in the control and experimental groups were determined using ANOVA, where the differences were considered significant at $P < 0.05$ (taking into account the Bonferroni Correction).

Results

We found that instrumentally-identified coefficients of daily emission of ammonia from the both sties into the air in the winter, spring, summer, and autumn periods were higher 1.5, 4.6, 5.7, and 3.7-fold,respectively, than the estimates. The coefficients of instrumentally-measured daily emissions of fine-dispersed dust ($PM_{1–10}$) were lower by 39.7–67.2 and 23.5–35.1-fold in winter and spring periods and 43.2–52.6 and 36.1–50.4-fold in the summer and autumn periods, respectively (Table 2).

The coefficient of daily methane emission and its CO_2-eqv was 1.8–3.9-fold higher in the premises with slatted floor, compared with concrete-floor sty (in the conditions of one-time removal of manure per day), which was associated with peculiarities of the self-cleaning technology of accumulation and removal of manure. Analysis of data in Table 3 indicated that the coefficient of daily emission of ammonia in the winter, spring, and autumn periods in the sty with slatted floor in the pens was significantly lower by 62.6% ($P < 0.001$), 17.0% ($P < 0.001$), and 43.5% ($P < 0.001$), compared with the premises with concrete floor. However, the coefficient of methane emission in the sty with concrete floor was significantly lower than in the premise with slatted floor by 76.1–286.9% ($P < 0.001$).

Two-times removal of manure from the sty with concrete floor in pens (Table 4) significantly decreased the mean-annual coefficients of emissions of carbon dioxide, ammonia, and methane, respectively by 12.1% ($P < 0.001$), 22.4 ($P < 0.001$), and 13.5% ($P < 0.001$). Also, there were 12.9%, 11.8%, 5.9%, and 23.4% decreases in CO_2-eqv methane in the winter, spring, summer, and autumn periods, respectively.

To achieve stable and proper air quality in premises, therefore providing high level of comfort for swine, it is important to know the patterns of emissions of some air contaminants over the periods of the year, their sources, mass concentrations, and dynamics of emission over a day period. Figures 2 and 3 demonstrate a graphic analysis of emissions of the main contaminants from sties with different types of floor in the pens, indicating a significant effect of this factor on the amount of their emission (1,554.5 to 1,745.2 g/day×100 kg of body mass) and its structure.

The study results meet the requirements of the 2019 EMEP/EEA air pollutant emission inventory guidebook, which emphasizes that "emission estimates should be accurate in the sense that they are systematically neither over nor under true emissions, as far as can be judged, and that uncertainties are reduced as far as practicable".

Discussion

Protection of the atmosphere in Ukraine is regulated at the legislative level and the normative documents. The level of atmosphere pollution in the industrial territory of pig farms and at the boundaries of sanitary-protection zones is determined using special calculation and instrumental methods. The criterion of assessing how emissions from farms affect the air is comparing actual concentrations (taking into account background concentrations) with threshold allowable concentrations in air in the settlements. Calculation of the general emissions from swine farms is carried out using specific parameters, provided in the collection. The data of the collection are used to conduct inventory checking of emission sources and determining total emissions of contaminants in the air at farms during state account in the sphere of air protection and estimation of ecological tax, paid for emissions into the air according to communiqué of Ministry of Environment of Ukraine as of May, 28, 2010.

Table 2
Comparing of mean coefficients of daily emission of contaminants from sties with slated and concrete floor, obtained using different methods (g/day×100 kg of body mass, n = 240, x ± SD)

Contaminant, mean daily coefficient (E)	Instrumental method by the seasons				Calculation method by the seasons			
	winter	spring	summer	autumn	winter	spring	summer	autumn
CO_2	1093 ± 12	1680 ± 12	1369 ± 16	1743 ± 20	–	–	–	–
NH_3	2.19 ± 0.01	6.72 ± 0.02	8.40 ± 0.07	5.40 ± 0.02	1.469	1.469	1.469	1.469
CH_4	69.1 ± 0.28	130.1 ± 0.41	303.1 ± 2.08	188.2 ± 1.72	–	–	–	–
$PM_{1–10}$	0.0310 ± 0.0006	0.0678 ± 0.0015	0.0529 ± 0.0007	0.0293 ± 0.0006	2.074	2.074	2.074	2.074

Table 3
Comparing of coefficients of daily emissions of contaminants from sties with different type of flood by the seasons (g/day×100 kg of body mass, n = 240, x ± SD)

Contaminant	Type of floor in pen	Season			
		winter	spring	summer	autumn
CO_2	concrete	1084 ± 16^a	1696 ± 11^d	1200 ± 33^b	1848 ± 34^e
	slatted	1102 ± 32^a	1663 ± 16^d	1539 ± 16^c	1638 ± 25^d
NH_3	concrete	2.70 ± 0.02^b	7.35 ± 0.02^g	5.80 ± 0.07^d	6.90 ± 0.03^f
	slatted	1.69 ± 0.01^a	6.10 ± 0.02^e	11.01 ± 0.07^h	3.90 ± 0.03^c
CH_4	concrete	34.2 ± 0.4^a	94.2 ± 1.1^b	124.5 ± 1.1^e	114.3 ± 1.2^d
	slatted	104.0 ± 0.3^c	165.9 ± 0.8^f	481.7 ± 3.8^h	262.1 ± 3.8^g
$PM_{1–10}$	concrete	0.0417 ± 0.0011^c	0.0815 ± 0.0024^f	0.0499 ± 0.0008^d	0.0400 ± 0.0010^c
	slatted	0.0203 ± 0.0007^b	0.0541 ± 0.0011^e	0.0559 ± 0.0011^e	0.0187 ± 0.0004^a

Note: different letters in column indicate that data sets are significantly different ($P < 0.05$) one from another according to the Tukey Test with the Bonferroni Correction.

Table 4
Comparing of coefficients of daily emission of contaminants from sties with concrete floor and one- and two-time removal of manure a day (g/day×100 kg of body mass, n = 240, x ± SD)

Contaminant	Removal frequency	Seasons			
		winter	spring	summer	autumn
CO_2	1	1084 ± 16^b	1696 ± 11^f	1200 ± 33^c	1848 ± 34^g
	2	1040 ± 22^b	1534 ± 14^d	931 ± 33^a	1620 ± 29^e
NH_3	1	2.70 ± 0.02^b	7.35 ± 0.02^h	5.80 ± 0.07^e	6.90 ± 0.03^g
	2	2.56 ± 0.02^a	6.82 ± 0.02^f	3.34 ± 0.05^c	4.91 ± 0.03^d
CH_4	1	34.2 ± 0.38^b	94.2 ± 1.09^d	124.5 ± 1.14^f	114.3 ± 1.21^e
	2	29.8 ± 0.53^a	83.1 ± 0.89^c	117.1 ± 3.18^e	87.6 ± 0.64^c
$PM_{1–10}$	1	0.0417 ± 0.0011^c	0.0815 ± 0.0024^f	0.0499 ± 0.0008^e	0.0400 ± 0.0010^c
	2	0.0327 ± 0.0011^b	0.0818 ± 0.0025^f	0.0462 ± 0.0003^d	0.0284 ± 0.0004^a

Note: see Table 3.

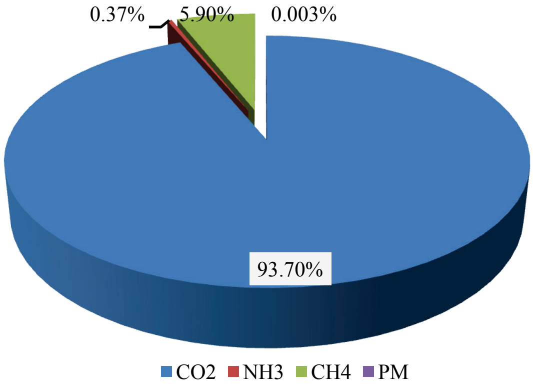

Fig. 2. Structure of emissions of the main contaminants (1554.5 g/day×100 kg of body mass) into the air from sty with concrete floor in pens, on average for the four seasons

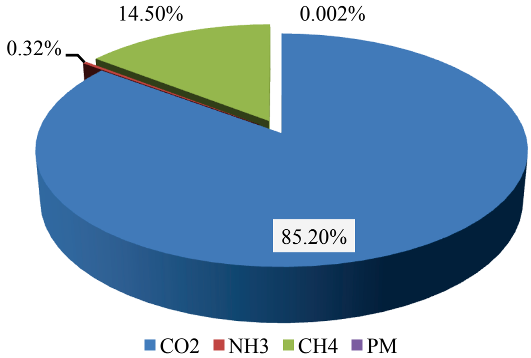

Fig. 3. Structure of emissions of the main contaminants (1745.2 g/day×100 kg of live mass) into the air from sty with slatted floor in pens, on average for the four seasons

The emission parameters that were developed, approved, and are used in Ukraine were analyzed, revealing that in general, they deal with contaminants from animal-farming complexes and animal farms with over 13 thou animals. At the same time, a growing development is currently seen for farms and other agricultural enterprises holding small animal-farming objects, with up to one thousand animals for which there are no existing scientifically substantiated emission parameters (specific emissions).

Therefore, at the current stage, there is a need to develop such scientifically-proven approaches in order to normalize emission of air contaminants from small farms with livestock.

The main sources of contaminant emissions on swine farms are premises for animals, exhauster ventilation, machines and equipment that use fuel, places of storage and processing of manure, and places of storage and processing of feeds (Gutyj et al., 2019; Borshch et al., 2021; Butsiak et al., 2021; Honcharova et al., 2021; Vasylyev et al., 2021). During storage and processing of manure and after it is introduced into the soil, it gives off a dangerous colorless gas – ammonia. It mainly forms from urine, which breaks down subject to anaerobic bacteria, during decay of nitrogen-containing organic compounds in sties, manure storages, and the soil. Ammonia causes tears, dizziness, acid reflux, irritations of the mucous membrane of the nasopharynx, sore throat when swallowing, headache, general weakness, locomotor impairments, sickness, vomiting, increased heart rate, seizures, and cardiovascular-system dysfunctions (Guthrie et al., 2018; Bardov et al., 2020; Bashchenko et al., 2020).

According to the literature data, biomethanogenesis involves methane-forming microorganisms, of which 30 to 50 species were identified. Optimal temperatures at which microorganisms live most actively, are 6.0 to 20.0 °C for cold-loving organisms, 32.0–33.0 °C for mesophiles, and 52.0–54.0 °C for thermophiles. The term "intestinal" methane, or enteral methane, indicates methane formed as a result of microbial fermentation in the gastrointestinal tract of animals (Harper, 2011). According to the data (Bardov et al., 2020), in storage places of solid and liquid manure (for example, in open lagoons, tanks, or pits) at the swine complexes, manure in anaerobic (without access to oxygen) conditions breaks down and can also produces a large amount of methane. Emissions of methane and other contaminants occur throughout storage (Barrington, 1999). Methane emissions affect people, causing lung edema, shortness of breath, increased heart rate, and headache. The main sources of emissions of nitrogen oxide (N_2O) are premises for animals, places of storage and processing of manure, and process of its introduction into soil. Nitrogen oxide is a poisonous gas. High concentrations can be a reason of asthmatic symptoms and lung edema. According to the literature data, CH_4 and N_2O have a greater – 21 and 310 times higher – potential for the global warming than CO_2 for hundred years, respectively, inferring from their ability to cause climate changes (Houghton et al., 1995; Mylostyvyi et al., 2021). Therefore, they are the main greenhouse gases promoting the global warming and climate changes on Earth.

It has to be noted that our data correlate with the results of foreign researchers (Bashchenko et al., 2009; Costa et al., 2013; Lagadec et al., 2013), in particular for ammonia 6.1–13.0 g/pig×day, 4.3–15.9 g/pig×day (Lagadec et al., 2013) and methane 24.6–77.1 g/pig×day (Costa et al., 2013). Our data, according to the parameters of fine-dispersed dust $PM_{1–10}$, approach the result of 0.2–2.7 g/pig×day (Costa et al., 2013). This may be associated with the differences in the natural composition, microclimatic differences between countries, complex action of technological factors such as systems of animal maintenance, ventilation, manure removal, feeding and watering (Donham, 2000), fluctuations in the daily activity of the experimental animals by seasons of the year (Kim et al., 2008) and specifics of constructive and volumetric planning solutions of the constructions.

Other than gaseous contaminants, the air is contaminated by microorganisms and dust from the premises, from preparation and storage of feeds, and from the skin and coats of animals. The factors promoting dust emissions include ventilation, vital activity of the animals, type and amount of the litter, species and consistency of feeds, and relative humidity in the premises for animals. Type of feed and feeding practice also affect the concentration of emissions. On swine farms, the main sources of formation of unpleasant odors in the air are emissions from the stationary sources, for examples, from manure storages and sties. Malodorous impact is also caused by malfunctioning or absence of a system of cleaning emissions, malpractice of storage, and use of liquid manure. Gaseous breakdown products give off an unpleasant odor, and dust coming from farms into the air spreads this smell to large distances. Presence of odor near a swine farm can also indicate non-adherence to boundaries of the sanitary-protection zone.

Conclusion

The studies of emission of contaminants from animal premises using the method of continuous automatic record allowed us to identify patterns of emissions of the main air contaminants and determine the daily coefficients of emissions, average-annual, and by year periods. The method of continuous automatic record revealed the coefficients of daily emission of carbon dioxide and methane from premises for fattening of young pigs, equaling 1471 g/day×100 kg of body mass and 173 g/day×100 kg of body mass, respectively. Coefficients of daily emissions of ammonia in the sty with slatted floor in the pens in the winter, spring, and autumn periods were significantly lower by 62.6%, 17.0% and 43.5% ($P < 0.001$) compared with the concrete-floor sty. However, coefficients of daily emissions of methane were significantly higher by 76.1–286.9% ($P < 0.001$), which was associated with peculiarities of the self-cleaning system of accumulation and removal of manure. Two-times removal of manure from the sties with concrete floor in the pens significantly reduced the mean annual coefficients of emissions of carbon dioxide, ammonia, and methane, respectively, by 12.1%, 22.4%, and 13.5% ($P < 0.001$). Analysis of emissions of the main contaminants from sties with different types of floor in the pens indicates significant effects of this factor on the amount of emission, its structure, and presence of seasonal variability in those parameters.

The authors declare that there is no conflict of interest.

References

Bardov, V. H., Omelchuk, S. T., & Merezhkina, N. V. (2020). Hihiiena ta ekolohiia [Hygieneandecology]. Nova Knyha, Vinnytsia (in Ukrainian).

Barrington, S. (1999). Comment se faitil que les gaz des fumiers liquides soient tellement nauséabonds? [Why do gases from liquid manure stink so much?]. Le Producteur de Lait Québécois, 20(3), 41–45.

Bashchenko, M. I., Boiko, O. V., Honchar, O. F., Sotnichenko, Y. M., Tkach, Y. F., Gavrysh, O. M., Nebylytsja, M. S., Lesyk, Y. V., & Gutyj, B. V. (2021). The cow's calving in the selection of bull-breeder in Monbeliard, Norwegian Red and Holstine breed. Ukrainian Journal of Ecology, 11(2), 236–240.

Bashchenko, M. I., Boiko, O. V., Honchar, O. F., Gutyj, B. V., Lesyk, Y. V., Ostapyuk, A. Y., Kovalchuk, I. I., & Leskiv, K. Y. (2020). The effect of milk thistle, metiphen, and silimevit on the protein-synthesizing function of the liver of laying hens in experimental chronic cadmium toxicosis. Ukrainian Journal of Ecology, 10(6), 164–168.

Bashchenko, M. I., Boiko, O. V., Honchar, O. F., Gutyj, B. V., Lesyk, Y. V., Ostapyuk, A. Y., Kovalchuk, I. I., & Leskiv, K. Y. (2020). The effect of milk thistle, metiphen, and silimevit on the protein-synthesizing function of the liver of laying hens in experimental chronic cadmium toxicosis. Ukrainian Journal of Ecology, 10(6), 164–168.

Bashchenko, M. I., Honchar, O. F., Lavrov, V. V., & Derii, S. I. (2009). Ekolohichna merezha Tsentralnoho Prydniprovia [Ecological net work of the Central Dnieper region]. Tsentr Ekolohichnoji Osvity ta Informatsiji, Kyiv (in Ukrainian).

Bashchenko, M. I., Voloshchuk, V. M., & Ivanov, V. O. (2021). Metodyka multyparametrychnoji otsinky mikroklimatu tvarynnyts'kykh prymishchen' metodom bezperervnoji avtomatychnoji rejestratsiji [The method of multiparametric assessment of the microclimate of livestock premises by the method of continuous automatic registration]. Cherkas'ka Research Station of Bioresources of NAAS, Cherkasy (in Ukrainian).

Bastviken, D., Nygren, J., Schenk, J., Massana, R. P., & Duc, N. T. (2020). Technical note: Facilitating the use of low-cost methane (CH_4) sensors in flux chambers – calibration, data processing, and an open-source make-it-yourself logger. Biogeosciences, 17, 3659–3667.

Borshch, O. O., Borshch, O. V., Sobolev, O. I., Nadtochii, V. M., Slusar, M. V., Gutyj, B. V., Polishchuk, S. A., Malina, V. V., Korol, A. P., Korol-Bezpala, L. P., Bezpalyi, I. F., & Cherniavskyi, O. O. (2021). Wind speed in easily assembled premises with different design constructions for side curtains in winter. Ukrainian Journal of Ecology, 11(1), 325–328.

Butsiak, H. A., Butsiak, V. I., Gutyj, B. V., Kalyn, B. M., Muzyka, L. I., Stadnytska, O. I., Luchyn, I. S., Rozputnii, O. I., Kachan, L. M., Melnichenko, Y. O., Sliusarenko, S. V., Bilkevich, V. V., & Leskiv, K. Y. (2021). Migration of mobile forms of heavy metals into the vegetative mass of plants under local human-caused load. Ukrainian Journal of Ecology, 11(1), 239–343.

Cardador, M. J., Reyes-Palomo, C., Díaz-Gaona, C., Arce, L., & Rodríguez-Estevez, V. (2022). A review of methodology for measuring greenhouse gas emissions in livestock production: Pig farms as a case study. Critical Reviews in Analytical Chemistry, 52(5), 1029–1047.

Chemela, C., Riesenmey, C., Batton-Hubert, M., & Vaillant, H. (2012). Odour-impact assessment around a landfill site from weather-type classification, complaint inventory and numerical simulation. Environ Manage, 93(1), 85–94.

Costa, A., Borgonovo, F., & Guarino, M. (2013). PM_{10} and greenhouse gases yearly emission factors measured in four different pig weaning rooms. International symposium on EMIssion of gas and dust from Livestock (EMILI 2012). Pp. 26–30.

Donham, K. J. (2000). The concentration of swine production: Effects on swine health, productivity, human health, and the environment. Veterinary Clinics of North America: Food Animal Practice, 16(3), 559–597.

Guthrie, S., Giles, S., Dunkerley, F., Tabakchali, H., Harshfield, A., Ioppolo, B., & Manville, K. (2018). Biodiversity impacts of ammonia emissions from agriculture. Reports of the Royal Society, Rand Corporation, Cambridge.

Gutyj, B., Ostapiuk, A., Kachmar, N., Stadnytska, O., Sobolev, O., Binksevych, V., Petryshak, R., Petryshak, O., Kulyaba, O., Naumyuk, A., Nedashkivsky, V., Nedashkivska, N., Magrelo, N., Golodyuk, I., Nazaruk, N., & Binkevych, O. (2019). The effect of cadmium loading on protein synthesis function and functional state of laying hens' liver. Ukrainian Journal of Ecology, 9(3), 222–226.

Harper, L. A. (2011). Micrometeorological methods of measuring intestinal emissions of greenhouse gases. Animal Feed Science and Technology, 166–167, 227–239.

Honcharova, O. V., Paraniak, R. P., Kutishchev, P. S., Paraniak, N. M., Hradovych, N. I., Matsuska, O. V., Rudenko, O. P., Lytvyn, N. A., Gutyj, B. V., & Maksishko, L. M. (2021). The influence of environmental factors on fish productivity in small reservoirs and transformed waters. Ukrainian Journal of Ecology, 11(1), 176–180.

Insausti, M., Timmis, R., Kinnersley, R., & Rufino, M. (2020). Improvements in the determination of ammonia from agricultural sources. Science of the Total Environment, 706, 135124.

Kim, K., Ko, H. J., Kim, H. T., Kim, C. N., & Byeon, S. H. (2008). Relationship between pig activity and environmental factors in pig housing. Australian Journal of Experimental Agriculture, 48(5), 680–686.

Lagadec, S., Landrain, B., Landrain, P., Robin, P., & Hassouna, M. (2013). Ammonia and greenhouse gas emissions in pig fattening on slatted floor with excrement discharge by flat scraping. International Symposium on EMIssion of Gas and Dust from Livestock (EMILI 2012). Pp. 58–61.

Mylostyvyi, R., Lesnovskay, O., Karlova, L., Khmeleva, O., Kalinichenko, O., Orishchuk, O., Tsap, S., Begma, N., Cherniy, N., Gutyj, B., & Izhboldina, O. (2021). Brown Swiss cows are more heat resistant than Holstein cows under hot summer conditions of the continental climate of Ukraine. Journal ofAnimal Behaviour and Biometeorology, 9(4), 21034.

Mylostyvyi, R., Sejian, V., Izhboldina, O., Kalinichenko, O., Karlova, L., Lesnovskay, O., Begma, N., Marenkov, O., Lykhach, V., Midyk, S., Cherniy, N., Gutyj, B., & Hoffmann, G. (2021). Changes in the spectrum of free fatty acids in blood serum of dairy cows during a prolonged summer heat wave. Animals, 11(12), 3391.

Nebylytsia, M. S., & Boiko, O. V. (2019). Obgruntuvaty vykorystannia rozpodilenoji systemy kontroliu povitrianoho seredovyshcha tvarynnytskykh prymishchen [Tojustifytheuse of a distributed aire nvironment control system of livestock premises]. Efektyvne Krolivnytstvo i Zvirivnytstvo, 5, 99–117 (in Ukrainian).

Nebylytsia, M. S., & Boiko, O. V. (2022). Mul'typarametrychna otsinka mikroklimatu tvarynnytskykh prymishchen' metodom bezperervnoji avtomatychnoji reiestratsiji [Multiparametric assessment of the microclimate of livestock premises by the method of continuo us automatic registration]. Svynarstvo, 77–78, 106–116 (in Ukrainian).

Phillips, V., Holden, M., Sneath, R., Korotky, J., Bely, R., Hartung, J., Seedorf, J., Schroeder, M., Linkert, K., & Pedersen, S. (1998). Development of reliable methods for measuring concentrations and emission levels of gaseous and solid air pollutants in livestock premises. Journal of Agricultural Engineering Research, 70, 11–24.

Reznikov, O. H. (2003). Zahalni etychni pryntsypy eksperymentiv na tvarynakh. Pershyi natsionalnyi konhres z bioetyky [General ethical principles of animal experiments. First National Congress on Bioethics]. Endokrynolohiia, 8(1), 142–145 (in Ukrainian).

Santonha, H. G., Georgitsikis, K., Scalet, B. M., Montabbio, P., Roudier, S., & Sancho, L. D. (2017). Best available technologies (BAT) reference document for intensive poultry or pig. Publications Office of the European Union, Luxembourg.

Schiffman, S. S., & Williams, C. M. (2005). Science of odoras a potential health issue. Journal of Environmental Quality, 34(1), 129–138.

Vasylyev, D., Priimenko, B., Aleksandrova, K., Mykhalchenko, Y., Gutyj, B., Mazur, I., Magrelo, N., Sus, H., Dashkovskyy, O., Vus, U., & Kamratska, O. (2021). Investigation of the acute toxicity of new xanthine xenobiotics with noticeable antioxidant activity. Ukrainian Journal of Ecology, 11(1), 315–318.

Zhukorskyi, O., Moklyachuk, L., & Nykyforuk, O. (2014). Emissions of air pollutants from area livestock industry in Ukraine. Agricultural Science and Practice, 1(2), 39–44.