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Analytical review

HEALTH RISKS POSED BY USING ORGANIC FERTILIZERS

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Agricultural production has been intensifying for a while and this has made for growing volumes of organic wastes; a part of them is later used as fertilizers. At present, more than 200 types of organic fertilizers are employed in agriculture; they differ in their origin, properties, and effects on the environment. Wastes from agricultural productions typically contain biocides, antibiotics included, and also, which is especially important, pathogens and opportunistic pathogenic microorganisms. Soil contamination with such wastes destroys natural biocenosis. Moreover, pathogens that remain in wastes due to absence of proper treatment can pose serious hazard for humans and animals. Safety of food products made of raw materials, growth of which relies on using organic fertilizers, is a significant component of the overall issue.

This analytical review provides a classification and descriptions of organic fertilizers and data on production volumes and accumulation of animal husbandry wastes. It also describes major biological and chemical factors of health risks associated with using organic fertilizers as well as provides the results of up-to-date studies that focus on negative effects of organic fertilizers. Special attention is paid to literature data about negative impacts exerted on human health and the environment by organic fertilizers that contain antibiotics and salts of heavy metals. It is emphasized specifically that organic fertilizers can very often contain copper, zinc, cadmium, nickel, chromium, arsenic, lead and mercury compounds. Improper use of technologies for treatment of organic fertilizers is shown to result in microbial and chemical pollution in soils and water objects. Methods employed to assess effects of animal husbandry wastes on human health and the environment are described considering international and Russian practices and documents that establish regulatory requirements to safe use of organic fertilizers. The review establishes that a strategy for providing safety of agricultural production should consider risks for human health and include systemic monitoring over quality of the environment and population health.

Keywords: *environment, agricultural productions, health risks, organic fertilizers, biocides, antibiotics, heavy metals, pathogens.*

Organic fertilizers are used in agriculture quite actively since they contain almost all essential plant nutrients and support recovery of certain elements in the biological cycle, which were previously taken from soils with crops [1]. In addition, organic fertilizers stimulate development of beneficial soil microorganisms providing access to essential nutrients for plants[1] [2]. Organic fertilizers can partially replace mineral ones due to their ability to increase soil biological diversity and, consequently, ensure more effective use of nutrients by crops [3, 4].

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[1] Vasil'ev V.A., Filippova N.V. Spravochnik po organicheskim udobreniyam [Reference book on organic fertilizers]. Moscow, Rosagropromizdat Publ., 1988, pp. 137–155 (in Russian).

The EU Regulation[2] defines organic fertilizers as animal by-products, which are subject to mandatory control within the environmental protection legislation as regards microbe and chemical contamination in them. In the Russian Federation since 2022, organic fertilizers have also been considered animal waste, which are covered by the requirements stipulated in the sanitary legislation in the sphere of waste treatment and disposal[3]. Agricultural production has been intensifying for a while and this has made for growing volumes of organic wastes, which typically contain biological, chemical and mechanical pollutants affecting the biosphere [5, 6].

Soil contamination with agricultural wastes is among the most widely-spread reasons for disorders of soil biocenosis since such wastes can contain toxicants, biocides, antibiotics included, and also pathogens and opportunistic pathogenic microorganisms. Presence of these negative factors determines quality of fertilizers, their influence on the environment and associated health risks. Food safety is another essential practical aspect of the issue. The overall scheme that illustrates how organic fertilizers (often referred to as (animal) manure) used in agriculture influence the environment and human health is provided in Figure 1. Human health largely depends on how well natural features of various environmental components are protected and maintained. Assessment of effects produced by animal manure can give ground for making improvements in the system for environmental pollution control.

Production volumes, classification and description of organic fertilizers based on animal manure. Growth in the agricultural sector supports the UN World Food Programme and helps achieve its goals. Still, the agricultural sector is a major source of pollution in soil and other environmental objects. Since 1980, the UN has been listing agricultural enterprises among four major health hazards. Wastes and sewage of agricultural

Figure 1. Effects produced by animal manure on the environment and human health [6]

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[2] Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation). *European Union: an official website*. Available at: http://data.europa.eu/eli/reg/2009/1069/oj (August 21, 2024) (in Russian).

[3] O pobochnykh produktakh zhivotnovodstva i o vnesenii izmenenii v otdel'nye zakonodatel'nye akty Rossiiskoi Federatsii: Federal'nyi zakon ot 14.07.2022 № 248-FZ [On animal husbandry by-products and on making alterations into certain regulatory documents of the Russian Federation: the Federal Law issued on July 14, 2022 No. 248-FZ]. *Ofitsial'noe opublikovanie pravovykh aktov [Official publications of legislative acts]*. Available at: http://publication.pravo.gov.ru/Document/View/0001202207140005 (August 21, 2024) (in Russian).

enterprises that use antibiotics, vaccines and farm chemicals and issues related to recycling / burying wastes, impossibility to perform total control at farms scattered around vast territories and many other factors lead to deterioration of the environment and undoubtedly affect human health [7].

Animal husbandry annually produces huge amounts of animal manure. According to expert estimations, in the United States, as much as 1.4 billion tons of manure is produced every year [8]. In Canada, animal manure consumption has grown practically by 60 % over the last decade and reached approximately 4.6 million tons in 2021. In 2016–2019, 1.4 billion tons of animal manure was produced every year in 27 countries of the European Union (EU) and Great Britain. In Russia, not less than 580 million tons of manure is produced at animal and poultry farms (160 million/m^3) and less than 50 % of it is used [7]. In some cases, agricultural enterprises violate environmental legislation by depositing manure on soil surface in amounts beyond safe standards for its use [9]. Environmental risk due to improper treatment and use of animal manure is established to exceed 85 % as regards all other possible risks. As a result, not less than 2.2 million tons of nitrogen and 0.36 million tons of phosphor enter the environment every year without any control [10].

At present, more than 200 types of manure are used in agriculture. They are extremely diverse as regards their origin, properties and effects on the environment. Manure is primary classified per its origin; that is, animal / bird species. Further classification is performed within each class per an age of manure receipt. If composting is performed, manure hazard class goes down from III (moderately hazardous) to V (practically not hazardous). Manure is also divided into granulated, powder-like and liquid types. Manure contains such essential plant nutrients as carbon, nitrogen, phosphor, potassium, calcium, and sulfur; their levels vary depending on origin [11, 12] (Table 1). But manure introduced in excessive quantities, which are above plant needs, becomes a pollutant that affects quality of agricultural and industrial sewage. This, in its turn, leads to eutrophication in water objects[4], pollution of subsoil waters [13] and ambient air[5].

Use of manure is a good alternative to use of inorganic fertilizers since high contents of essential nutrients in the former and their emission for a long time create high levels of total nitrogen in soil, greater quantity, biomass and diversity of soil bacteria against mineral fertilizers [14]. Nevertheless, use of fresh or improperly composted manure can damage

Table 1

Manure chemical composition, %

Manure type, origin	Humidity	N_{total}	P_2O_5	K_2O	CaO	MgO
Chicken	73.0	1.50 ± 0.2	1.40 ± 0.2	0.50 ± 0.1	1.10 ± 0.4	0.70 ± 0.1
Duck	80.0	0.60 ± 0.1	0.80 ± 0.3	0.30 ± 0.1	1.00 ± 0.2	0.20 ± 0.1
Goose	82.0	0.50 ± 0.1	0.50 ± 0.1	0.80 ± 0.1	0.60 ± 0.1	0.20 ± 0.1
Turkey	64.0	0.70 ± 0.2	0.60 ± 0.1	0.50 ± 0.1	0.50 ± 0.1	0.20 ± 0.1
Cattle	77.3	0.50 ± 0.1	0.25 ± 0.1	0.40 ± 0.1	0.40 ± 0.2	0.11 ± 0.1
Small cattle	64.6	0.83 ± 0.1	0.23 ± 0.1	0.67 ± 0.1	0.33 ± 0.1	0.18 ± 0.1
Horse	71.3	0.58 ± 0.1	0.28 ± 0.1	0.63 ± 0.1	0.21 ± 0.1	0.14 ± 0.1
Pig	72.4	0.45 ± 0.1	0.19 ± 0.1	0.60 ± 0.1	0.18 ± 0.1	0.09 ± 0.1

Note: generalized data provided by Pryanishnikov Institute of Agrochemistry and Russian Scientific Research Institute for Manure and Peat.

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[4] Carpenter S.R., Caraco N.F., Correll D.L., Howarth R.W., Sharpley A.N., Smith V.H. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, 1998, vol. 8, no. 3, pp. 559–568. DOI: 10.2307/2641247

[5] Ryden J.C., Skinner J.H., Nixon D.J. Soil core incubation system for the field measurement of denitrification using acetylene-inhibition. *Soil Biol. Biochem.*, 1987, vol. 19, no. 6, pp. 753–757. DOI: 10.1016/0038-0717(87)90059-9

soil microbiota due to introduction of pathogenic microorganisms, pathogenicity and antibiotic resistance genes as well as wide ranges of antibiotics and anti-parasitic drugs, heavy metals and hormones. All this produces negative effects on soil bacteria and, most importantly, causes environmental risks for human health.

Risks associated with use of animal manure. Quantitative and qualitative composition of soil bacteria is a major indicator employed to estimate soil stability and fertility [15]. In most cases, manure introduction has favorable effects on biomass and diversity of soil microbiota; however, excessive introduction of organic substrate can lead to soil deterioration and its poorer quality associated with intensive reproduction of certain bacteria groups, pathogens included.

Introduction of infectious agents into soil. The number of pathogens introduced into the environment is a significant indicator in assessing health risks associated with manure use. Animal feces contain bacteria, viruses, protozoa and helminthes. Thus, together with benign microbiota, manure can contain pathogens and opportunistic pathogenic microorganisms including *Escherichia coli, Shigella* spp., *Clostridium botulinum, Clostridium perfringens, Salmonella enterica* subsp. *enterica* serotype Enteritidis, *Salmonella* Virchow, *Campylobacter* spp., *Listeria monocytogenes*, *Yersinia enterocolitica* and protozoa, in particular, *Cryptosporidium parvum* and *Giardia lamblia* [16–18] (Table 2). Such fungi as *Ascomycota* and *Basidiomycota*, some species of which are pathogenic for humans, can also be present in manure [19]. In case manure is not treated properly, pathogens can cause risks for human health. Animals are known to be the major reservoir of diarrheagenic *E. coli* (DEC), Shiga toxin producers *E. coli* O157:H7 and extraintestinal pathogenic *E. coli* (ExPEC).

According to a study performed by L.V. Pilip and N.V. Syrchina (2022), microbiocenosis of feces sewage mostly consisted of *Peptostreptococcus anaerobius* (58.2 %) and *Peptoniphilus asaccharolyticus* (41.6 %) species. However, opportunistic pathogenic microorganisms were also identified in it including *Enterococcus* spp., *E. coli*, *Klebsiella* spp., *Clostridium* spp., *Staphylococcus epidermidis*, *Proteus* spp., *Prevotella bivia*, *Alistipes putredinis*, *Staphylococcus aureus*, *Candida* spp. The number of sanitarily significant microorganisms *E. coli* and *Clostridium* spp. equaled $5.0 \cdot 10^6$ CFU/g and $7.0 \cdot 10^5$ CFU/g respectively [20]. Manure from hog productions in East Canada was found to contain high concentrations of certain pathogens including *Campylobacter* spp., *Clostridium perfringens*, *Enterococcus* spp., *E. coli*, *Salmonella enterica*, *Yersinia enterocolitica*, as well as *Giardia* and *Cryptosporidium* representatives [21]. Results obtained by our analysis of manure samples, which were different per storage periods and conditions, also indicate that coliform bacteria are present in impermissible quantities in fresh (non-composted) manure. In addition, regardless of storage periods, poultry manure was established to contain a high titer of *E. coli* with determinants of diarrheagenic and extraintestinal *E. coli*

Table 2

The number of pathogens and opportunistic pathogenic microorganisms in some manure types (CFU/g of fresh manure) [18]

Type	Coliforms	*Enterococcus* spp.	*Escherichia coli* O157:H7	*Salmonella* spp.	*Campylobacter* spp.
Poultry	$1.3 \cdot 10^6 – 1.4 \cdot 10^8$	$6.2 \cdot 10^5 – 1.9 \cdot 10^8$	Not identified	$4 \cdot 10^3$	$8.5 \cdot 10^8 – 10^9$
Pig	$2.4 \cdot 10^3 – 5.9 \cdot 10^6$	$5.0 \cdot 10^4 – 7.2 \cdot 10^4$	$1.3 \cdot 10^3$	$< 1.5 \cdot 10^3$	$6.1 \cdot 10^2$
Cattle	$< 1.0 \cdot 10^9$	-	$< 2.4 \cdot 10^3$	< 1 to 10^5	$6.9 \cdot 10^1 – 3.2 \cdot 10^5$
Sheep	$6.0 \cdot 10^6$	$6.6 \cdot 10^5$	$2.5 \cdot 10^2$	$5.8 \cdot 10^3 – 2.0 \cdot 10^4$	$10^1 – 10^5$
Horse	$9.4 \cdot 10^4$	$6.3 \cdot 10^6$	-	-	$9.4 \cdot 10^4$

pathotypes. Some microorganisms, upon introduction in soil with manure, can persist there for a long time. Manure is shown to be not only a source of pathogenic bacteria but also a factor able to promote their survival in soil biocenosis [22].

Human health risks are largely associated with fresh (non-composted) manure, use of which promotes introduction of pathogenic bacteria in soil [23]. The number of infectious agents was shown to grow substantially under poultry housing areas and adjacent pastures [12]. Studies performed in Maryland (USA) in 2007–2016 established a strong positive correlation between campylobacteriosis incidence and high quantities of large broiler chicken operations in the region [24]. Pneumonia risks were established for people living in regions with developed animal husbandry. Thus, in Germany, elevated prevalence of respiratory diseases and lower life quality were established for residents in areas with high density of animal farms and in close proximity to them [25]. High pneumonia incidence was also detected among adults living within 1-km radius from poultry farms [26, 27]. In addition, most examined patients had *Streptococcus pneumoniae* cultures in the oropharyngeal microbiota, which increased pneumonia risk [26]. An observation study that included 140,000 patients gave evidence of a relation between developing community-acquired pneumonia and proximity to poultry and cattle farms [28].

Apart from bacterial pathogens, organic fertilizers can contain protozoa (*Cryptosporidium* spp. and *Giardia* spp.) and also viruses, for example, coronaviruses, retroviruses, and avian influenza viruses that can be transmitted to humans with drinking water. Use of fresh (non-composted) poultry manure increases risks of these viruses being transmitted thought the nasal mucosa or conjunctiva. According to the European Center for Disease Prevention and Control, people who have direct and long-term contacts with infected poultry (mostly farm and slaughterhouses workers and those who deal with killing infected birds) belong to risk groups as regards occupational diseases, avian influenza in particular [29].

Introduction of antimicrobial resistant bacteria into soil and spread of antibiotic resistance genes (ARGs). Active use of antibiotics in animal husbandry supports developing resistance to them in animal microbiota. Agricultural wastes are a source of antimicrobial resistant bacteria, which increase a so called ‘resistance reservoir’ of soil microbiome and also support wider spread of antibiotic resistance genes in the environment [30]. Most antimicrobial drugs are common for veterinary medicine and healthcare and this is a serious challenge. Over the last years, multiple research data have been obtained indicating that soil microorganisms have variable antibiotic resistance genes and this concerns not only drugs, which have been used in healthcare for a long time, but also new ones, which have been introduced only recently [31–33].

According to our studies, most *E. coli* and *Pseudomonas* spp. cultures isolated from cattle and poultry manure had a phenotype of multidrug resistance; they also carried genes of beta-lactamases, QnrB and QnrS proteins responsible for resistance to fluoroquinolones as well as determinants of efflux pumps. Genes that determine resistance to veterinary antibiotics (those used in animal feed) from the Tetracycline group, Sulfanilamides and Macrolides were found in 94.7 % of analyzed manure and the *tet*(X) gene associated with resistance to Tetracyclines was the most widely spread [34]. The metagenomic sequencing showed that a total of 79 types of ARGs were found in soil cores (at depth of 0–20 cm, 20–40 cm and 40–70 cm) and the irrigation water (swine wastewater). Compared with the vegetable fields without animal manure application, the soils irrigated with swine wastewater harbored higher diversity of ARGs and integrons [35]. Similar data were obtained by Y.-G. Zhu with colleagues (2012), who identified 149 antibiotic resistance genes and the *aphA3* aminoglycoside phosphotransferase gene in all analyzed manure samples [36]. Extended spectrum beta-lactamase CTX-M type genes were prevalent in *E. coli* isolates obtained from swine manure and soils at swine farms [37]. One-year use of fresh chicken manure led to a considerable increase in genes associated with resistance to Tetracycline, such as *tetX*, *tetG*, *tetA* and *tetC* in a Chinese region. On the contrary, levels of antibiotic resistance genes were practically 50 % lower in soils fertilized with decomposed chicken manure [32]. In addition, the number of antibiotic resistance genes and levels of antibiotics in soil go down with increased distance from fertilized fields [38].

It is noteworthy that introduction of organic fertilizers into soil not only promotes local levels of mobile genetic elements but also increases frequency of horizontal gene transfer within an ecosystem [30]. Introduction of piggery manure was established to promote spread of plasmids in agricultural soils. Those plasmids belonged to a wide range of hosts (IncN, IncW, IncP-1 and pHHV216) carrying ARGs. [39]. Apart from antibiotic resistance determinants, natural microorganism strains can get genes associated with virulence due to horizontal gene transfer. These genes are usually located in distinct genetic elements on a chromosome, which are called ‘pathogenicity islands’ (PAI). Some known PAIs include the type III secretion system (e.g. LEE PAI in pathogenic *E. coli* and Hrp PAI in *Pseudomonas syringae*), toxins, colonization factor, and iron uptake systems [40]. According to A.K. Meneghine and others (2017), genes of potential virulence are often found in soils near animal farms [41]. Most detected genes were associated with transposons or integrons; bearing this in mind, we can expect that horizontal transfer of these elements to bacteria adapted to soil supports environmental transmission of antibiotic resistance and pathogenicity genes in the environment independent of the original host [42].

Therefore, spread of antibiotic-resistant opportunistic pathogenic and pathogenic bacteria in the environment is a serious challenge associated with wide use of antimicrobial drugs in agriculture. It becomes truly relevant in the view of increasing health risks due to likelihood of severe communicable diseases that are very hard to treat.

Accumulation of antibiotics in soil. Pharmaceutical drugs, first of all, antibiotics, are widely used in animal husbandry. Penicillins, Tetracyclines and Sulfonamides are the most common drug groups since their consumption accounts for 31, 27 and 10 % of all employed drugs respectively [43]. Many antibiotics are poorly adsorbed in the gut of the animals and only partially metabolized. According to expert estimates, up to 90 % of the active substance can be excreted unchanged in feces and urine and enter the environment [44, 45]. It is noteworthy that Tetracyclines and Sulfonamides are highly mobile and can persist in soil for a long time; due to it, they become an additional selective factor able to promote antibiotic resistance in bacteria strains.

Thus, antibiotics were detected in 55 % of the swine manure samples and in 75 % of the cattle manure samples [46]. Tetracyclines, Quinolones, Macrolides and Lincomycin were found more frequently than others. Some samples were found to contain from three to eight various antibiotics. Identified antibiotic levels varied between trace quantities and hundreds of μg/g. Other researchers also reported high concentrations of Tetracycline group (Tetracycline, Oxytetracycline and Doxicycline, between 53 and 541 μg/g) [47]. Data reported in multiple studies, that were conducted in 20 countries (mostly, in the USA, China, Canada, Spain, and Germany), and published between 1980 and 2019 (104 articles) give evidence of Sulfametazine, Sulfadiazine, Chlortetracycline, Oxytetracycline, and Tetracycline being detected in organic fertilizers most frequently [48].

Organic wastes can enter water and soil ecosystems as a result of violated sanitary-hygienic requirements. Levels of antibiotic contamination in soil can be rather high and depend on several reasons. Some authors believe the highest antibiotic levels to be detected in upper soil layers; others think that they largely persist in the deeper soil [49–51]. Persisting in soil, antibiotics can affect the structure and functions of soil bacterial communities and also promote generation and spread of antimicrobial resistance to such drugs [5, 32]. In addition, low antibiotic concentrations are known to induce spontaneous mutagenesis and resistant bacteria strains spread in the natural environment quite actively [52]. It should be noted that antibiotics, while persisting in soil for a long time, can enter the human body with food products [44].

Therefore, the highest antibiotic contamination is detected in soils enriched with poultry and swine manure. Long-term persistence of such drugs in high concentrations in soil does not only create high health risks but also promotes active spread of antimicrobial resistance in bacteria.

Accumulation of heavy metals. Heavy metals account for a considerable proportion of environmental pollutants; they hold the second place per their hazard for human health following carcinogenic hydrocarbons. Organic fertilizers can contain salts of copper (Cu), zinc (Zn), cadmium (Cd), nickel (Ni), chromium (Cr), arsenic (As), lead (Pb), and mercury (Hg) [53, 54] (Table 3). As metals accumulate in soils reaching a toxicity level, they start to produce negative effects on quality of the environment. Upon intake with water or food, heavy metals can pose a serious hazard for human health [55, 56].

Commercial feeds are a major source of heavy metals in manure [53, 54]. Organic arsenic compounds have been used as growth-stimulating feed additives for a long time in many countries[6]. Zn, Cu, As and Cd are used as feed additives in commercial feeds to stimulate animal growth as well as to raise resistance to infections [57–59]. In the EU, 150 million pigs consume more than 6.2 million tons of Cu through feed additives [60]. Animals excrete heavy metals in urine and feces [58]. Since metals are not degradable, they persist and accumulate in soil [60, 61].

Risks for human health caused by heavy metals depend on their levels in the environment and duration of exposure. It is noteworthy,

Table 3

Maximum (max) and minimal (min) levels (mg/kg dry weight) of heavy metals in various animal and poultry manure [54]

Source	Level	Metal							
		Zn	Cu	Pb	Cd	Cr	Hg	As	Ni
Pig	max	4638.72	1288.00	22.88	59.66	85.23	0.31	89.30	18.97
	min	100.26	72.66	0.27	0.04	3.53	0.00	0.00	4.67
Chicken	max	578.00	314.00	32.58	4.09	250.61	0.54	23.260	39.31
	min	165.68	18.24	2.99	0.03	4.00	0.02	0.05	5.21
Duck	max	682.10	198.76	40.79	2.53	63.61	0.07	6.83	16.12
	min	97.82	34.68	4.51	0.29	6.60	0.03	0.01	8.37
Poultry*	max	682.10	314.00	40.79	4.09	250.61	0.54	23.26	39.31
	min	77.42	14.71	2.04	0.03	2.50	0.02	0.01	5.21
Cattle	max	816.24	173.60	32.31	3.40	79.38	0.60	6.33	18.86
	min	48.72	12.28	1.64	0.04	0.76	0.02	0.01	4.19
Sheep	max	431.70	214.70	19.80	1.40	22.19	2.39	2.60	12.40
	min	42.38	8.37	1.74	0.28	8.00	0.19	0.59	1.22

Note: *excluding chicken and duck manure (goose, pigeon, etc.).

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[6] National Research Council. Arsenic: Medical and Biologic Effects of Environmental Pollutants. Washington, National Academies Press Publ., 1977, 340 p. DOI: 10.17226/9003

that even low-dose exposures to heavy metals can induce pathological processes in case they are long-term and repeated. Many heavy metals have been established to produce neurotoxic, nephrotoxic, cardiotoxic and hepatotoxic effects; in addition, heavy metals modulate immunologic tolerance, affect the reproductive function and also produce carcinogenic and genotoxic effects [55] (Figure 2). Thus, heavy metals induce DNA damage by generating reactive oxygen species, which can promote protumorigenic signaling, facilitating cancer cell proliferation [62]. Moreover, heavy metals inactivate the regulatory proteins p53 and p21 involved in DNA reparation as well as in the cellular cycle regulation. This stimulates cell dedifferentiation and malignant transformation [63].

As regards safety, elevated levels of heavy metals in manure can cause risks for soil microorganisms and, consequently, soil quality in long-term outlook and, in addition, promote occurrence of metal-resistant bacteria. In addition to destabilizing the microbial composition, heavy metal contamination in soil helps toxicants to penetrate food chains and thereby enter the human body. This results in growing incidence and declining life expectancy.

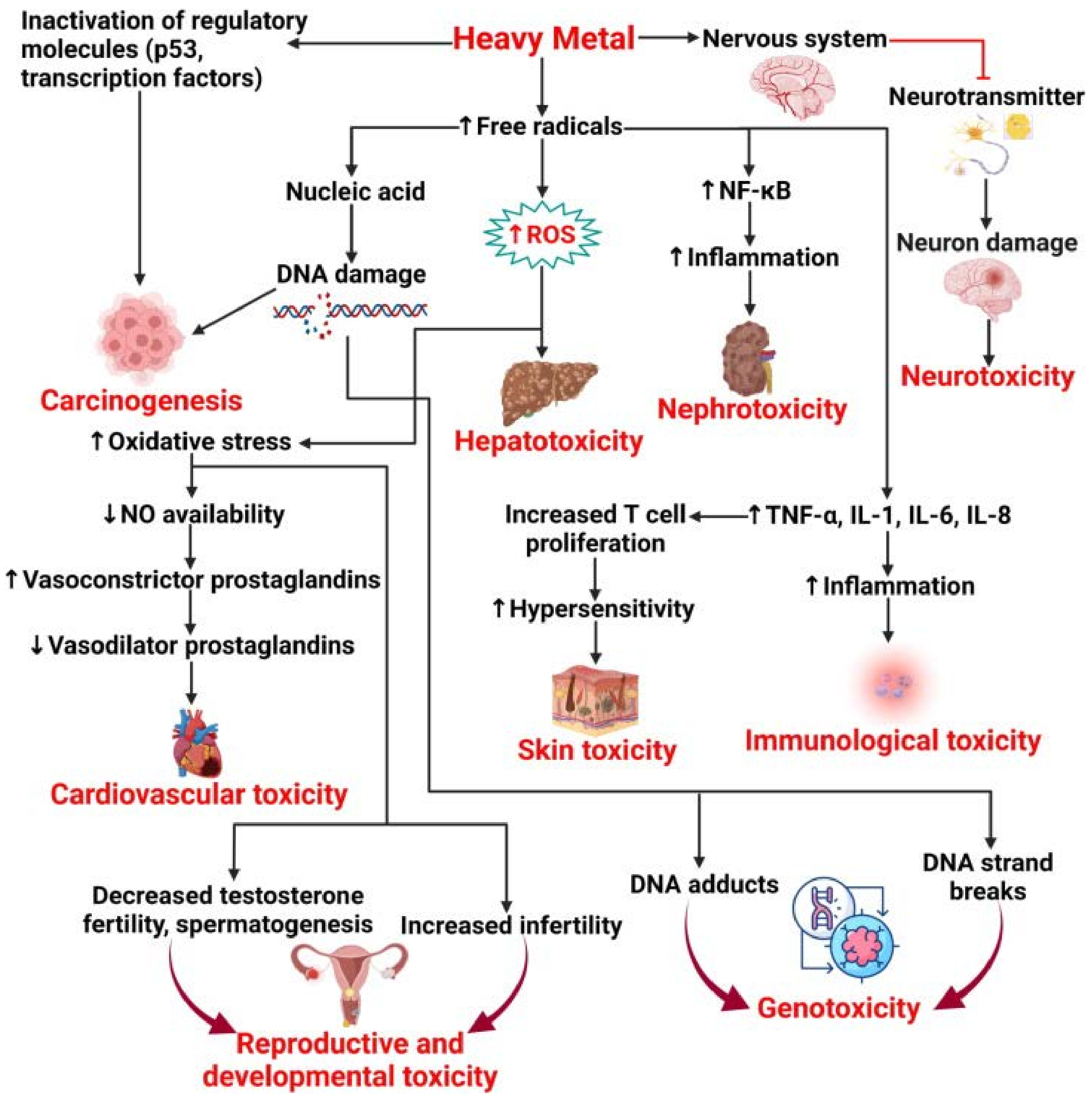

Figure 2. Toxicity of heavy metals for humans [55]

Methods for assessing influence and animal husbandry waste on human health and the environment. First methods for detecting and identifying human health hazards associated with unfavorable environmental exposures were developed in the USA and Europe; in addition, first techniques were created to estimate likelihood of unfavorable health outcomes. In 1970ties, the expert team headed by Doctor L.C. Robbins presented the first charts of possible health hazards, described relevant tools for research in the sphere, presented methods for assessing risk scopes and for establishing feedback with a patient[7]. Later, multiple programs and basic instruments for health risk assessment were created. At present, approaches and practical tools for assessing human-induced effects, agriculture included, on the environment and human health are extremely diverse [64, 65]. They are classified into eight discrete methods: health risk assessment (HRA), health impact assessment (HIA), environmental impact assessment (EIA), environmental burden of disease (EBD), lifecycle assessment (LCA), integrated assessment modeling (IAM), trade-off analysis (TOA), and economic assessment (EA). In addition, cumulative risk assessment (CRA), based on HRA, is used; it involves identifying amount of hazard for human health [64].

When interpreting these methods, we should emphasize that the first two ones are primary. HRA-investigations are accomplished in several stages and include hazard identification and characterization; exposure assessment; risk assessment or characterization and risk communication. This approach is limited by failure to consider social or economic aspects when accomplishing HRA. The second procedure, HIA, is aimed at optimizing methods for examining effects produced by a certain factor on human health without medical interventions, namely, data collection and interpretation to make a decision on relevant strategies or programs aimed at mitigating this negative factor or enhancing positive health effects.

The Russian legislation contains regulatory documents and methodical guidelines that regulate industrial operations, agricultural ones included, and determine relevant methods for assessing health risks associated with various exposures in conformity with the requirements stipulated in the SanPiN (Sanitary-Epidemiological Rules and Norms) 2.2.1/2.1.1.1200-03 Sanitary Protection Zones and Sanitary Classification of Enterprises, Constructions and Other Objects[8]. These requirements for animal and poultry farms are fixed in Alterations and Supplements No. 3 (approved by the Order of the RF Chief Sanitary Inspector on September 09, 2010 No. 122)[9]. Health risks caused by potential exposure to contaminants in food products are assessed in conformity with the Methodical Guidelines (MU 2.3.7.2519-09)[10] and The Guide on Assessing Health Risks caused by Exposure to Chemical Pollutants in

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the Environment (R 2.1.10.1920-04)[11]. The latter is a fundamental document that stipulates the essentials of assessing risks caused by exposures to chemical pollutants in the environment in conformity with the international health risk assessment methodology upon chemical exposures [66]. The Federal Law No. 248-FZ issued on July 14, 2022[12] regulates issues of control over manure as regards microbial and chemical contamination. It is these characteristics that determine manure quality and its influence on the environment.

At present, the overall state policy in Russia sets the following task: to implement the best available technologies (BATs) in industry and agriculture. Five reference books for agriculture have been compiled since 2017. The Institute for Agricultural Engineering and Environmental Issues together with the RAS Institute for Lake Studies has proposed an original method for overall assessment of environmental risks in order to predict unfavorable influence of animal husbandry farms on the environment. A program for agricultural monitoring and management of biogenic burdens has been created. It proposes complex assessment of additives toxicity combining chemical and eco-toxicological data. Another recommendation is to consider sensitivity and threshold levels of chemicals for different living organisms and to identify pathways of their adverse effects.

Therefore, the methodology for analyzing (assessing, managing and communicating) health risks caused by exposure to harmful pollutants in the environment is a complex systemic process. It involves the maximum possible expansion of characteristics of complex environmental pollution; within the process, it is necessary to get a more profound insight into possible nature and outcomes of negative effects produced by identified factors on the human body [67]. Despite all significant advances achieved by foreign and Russian researchers in agricultural ecology, a lot of issues remain unresolved as regards medical aspects of this topical challenge, in particular, emergence and spread of new hazardous agents of zoonotic infections.

Conclusion. The major goal to be achieved by providing ecological safety and sanitary-epidemiological wellbeing of population is to protect human life and health. A balanced and integrated risk-based approach to agricultural operations is based on One Health concept introduced by the WHO to optimize the health of people, animals and ecosystems. On one hand, it allows considering health risks; on the other hand, it creates opportunities for sustainable development of the UN World Food Programme.

Organic fertilizers are a potential source of environmental pollution, which is associated with a failure to conform to safe technologies for manure management. Both microbial and chemical pollution in soil and water objects pose health hazards. Any strategy aimed at providing safety of agricultural production should be developed with mandatory consideration of involved health risks as well as environmental and health monitoring.

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