Analysis of Feed as an Ecological Factor of Influence on the Organism of a Productive Animal under Conditions of Increased Anthropogenic Load on Agroecosystems

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Abstract. *Feed for farm animals is an environmental factor that has a significant impact on various physiological functions, productivity, health, and homeostasis of the body. It is the subject of research in many sciences, including ecology. Scientists in different countries of the world have begun to pay special attention to the study of the ecological safety of animal feed, which is associated with the urbanization of settlements, the development of industry, oil and gas production, accidents on main gas pipelines, mining of coal and gas, the placement of agricultural land by large cars, and livestock farms not far from the developed industrial center of metallurgical complex enterprises, etc., which leads to soil pollution with toxic heavy metals, and then migration and accumulation of elements in plants from the produced feed included in the rations. The aim of the research was to establish the quality and biological completeness of feed rations of dairy cows in enterprises located near environmentally unfavorable anthropogenic objects. The object of research included norms of rations, corn silage, alfalfa haylage, corn turf, fodder beets, grain hay, cereals and legumes hay, alfalfa hay. To conduct a scientific experiment on the production of cow's milk, plant-based feed from four farms located around an industrial city and not far from sources of anthropogenic pollution was selected. Laboratory analysis of selected average feed samples for the content of mineral elements, including toxic metals Cd and Pb, was carried out by the atomic absorption method. Statistical data processing was carried out using the STATISTICA software package version 10.0. The analysis of feed shows not only an increased concentration of heavy metals, but also a low content of vital essential macro- and microelements in plants (feed) against this background, which was typical for all farms. In such conditions, the problem of producing high-quality biologically valuable ecologically safe milk arises. Therefore, in case of local contamination of agroecosystems and ration feeds with heavy metals, especially Cd and Pb, it is necessary to take into account the actual nutritional value of feed, ensure the rationing of essential and non-essential elements in the diet and develop new feed additives, mineral and vitamin premixes of antidote action, homeostasis of an intoxicated organism, increasing the productivity of cows, improving their health status and obtaining environmentally friendly milk. Further research is aimed at constant environmental monitoring of various mineral elements, primarily toxic heavy metals in the feed of farms specializing in milk production in different regions of Ukraine, forest-steppe and Polissya.*

Introduction

Feed is the subject of research in many sciences, including ecology. The feed eaten by animals is considered as a link in the biotic circulation and as an integral part of the biogeochemical trophic chain in the agroecosystem. In a narrower essence, feed is a biogeocenosis factor that affects the animal population, species, individual, their organs, tissues, cells and subcellular structures. Many microminerals play an important role in the organism as cofactors for enzymes involved in controlling free radicals in the organism and are vital for antioxidant capacity. These same minerals, when consumed in excess, can become prooxidants in the body, generating destructive free radicals. Complex interactions between minerals can jeopardize the effectiveness of feeding in promoting health and improving performance of a dairy cow (Jesse, 2018). Today, the ecological study of animal feeding is to a certain extent based on data on feed production and feeding (trophology), since feed is the basic object of research in these sciences.

Ecology and feeding pay great attention to increasing the efficiency of bioconversion, i.e., converting the organic matter of plants into zoo mass (meat, milk, eggs, wool, etc.). In this case, migration during bioconversion of heavy metals, especially cadmium, lead, copper and zinc, plays an important role.

Scientists (Hejna et al., 2018) point to the need to develop new approaches to the ecology of animal feeding containing heavy metals and to constantly monitor environmental pollution by pollutants, especially in those industries related to animal husbandry. Controlling the intake of various mineral elements, including toxic metals from animal feed, can be an effective strategy to reduce health risks

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for humans consuming animal products, as well as soil contamination with animal waste. According to scientists (Hejna et al., 2018), legal restrictions on the content of certain pollutants in feed will also have a positive effect on their distribution in the components of the biosphere and migration in the food chain.

Feed and diet terms are certainly not identical, but they have a lot in common. Their commonality lies in the fact that both feed and diet are objects of animal feeding. During the period when dangerous toxicants of ecocidal origin such as Cd, Pb, Cu, and Zn enter the body of animals, attention to the structure of diets and their composition and nutritional value increases significantly, which is due to the production of environmentally friendly products (milk) containing xenobiotics within the established permissible levels. Therefore, experts in the animal husbandry industry (zoological engineers, veterinarians and production technologists) make up rations, balancing them in terms of energy content, dry matter, feed units, digestible protein, that is, proteins, fats, carbohydrates and other components of macro- and microelements. Scientists (Song Ren-ju et al., 2015) indicate that the relationship between micronutrient content in feed and milk can provide a theoretical basis for dairy farming, which would be beneficial to increase milk yield and quality of milk and dairy products produced.

The diet of feeding is a complex ecological factor, consisting of various substances, each of which has specific properties in terms of the nature of the impact and, therefore, is an independent ecological factor. The feed factors of the diet affect the animal organism not in isolation from each other, but in aggregate and in the corresponding interdependence, where antagonistic and synergistic properties are manifested, for example, between macro- and microelements, which is very important in case of intoxication of the body with contaminated feed that gets into the diet with time of feeding the animals.

It has been established that feed has a significant effect on animals, their productivity, quality and environmental safety of products, not to mention reproductive ability, population resistance or its sensitivity to various diseases, which may be accompanied by the consumption of feed containing toxic metals such as cadmium and lead and other elements in concentrations exceeding permissible levels. Scientists from China (Hui Wang et al., 2013) have examined 360 samples of feed and manure collected from 150 livestock farms in Jiangsu province, an area of intensive livestock farming, and analyzed them for the content of heavy metals and various mineral elements. Any food containing any chemical element above the maximum permissible concentration in the diet will serve as a limiting factor that will lead to the depression of the animal's condition and the production of low-quality products, and possibly even the disease of the animal due to loss of appetite and live weight, hypo-, hypervitaminosis and hypo-, hyper-, macro-, microelementosis, accompanied by general dystrophy, impaired hair growth, decreased skin elasticity, pallor of mucous membranes, the development of anemia, etc.

The aim of research is to establish the quality and biological value of feed, which are part of the diet of dairy cows at various agricultural enterprises located around an industrial city and near other ecologically unfavorable anthropogenic objects.

Material and methods

To conduct scientific and economic experience in the production of ecologically safe cow's milk and approbation of premixes and a biological product antidote to the action of toxic metals, samples of various forages of plant origin were taken, which were part of the main diet of animals in four commercial farms: a specialized agricultural enterprise "Druzhba", agricultural production cooperative "Khoroshkivsky", agricultural limited liability company "Svitanok", and agricultural limited liability company "Udai". Agricultural lands are located around the industrial city and near ecologically harmful anthropogenic objects of influence on agroecosystems, i.e. highways with increased traffic of motor transport Kyiv – Kharkiv – Dovzhanskyi, natural gas production fields and gas condensate enterprises, main oil and gas pipelines, enterprises for the production of asphalt concrete.

According to the ecological-meteorological-topographic scheme of research using the terrain map in Google, the Udai enterprise is located within a radius of 15.3 km from the main sources of pollution of the industrial city, "Druzhba" 8 km, "Svitanok" 13.9 km, "Khoroshkivsky" 25.7 km, respectively. Agricultural lands are located at a distance of several kilometers from the highway Kyiv – Kharkiv – Dovzhanskyi in the farms "Udai" and "Druzhba". In the farm "Khoroshkivsky", agroecosystems are located at a distance of 10 km from the gas condensate plant, and in the farms "Druzhba" and "Udai", they are near the main gas pipeline.

In the first farm, 36 heads of cows of Ukrainian black-spotted and red-spotted dairy breed with silage-root type of feeding were selected for experiment; 195 heads of cows of black-spotted dairy breed with silage-hay type of feeding were selected in the second; 63 dairy cows of the Ukrainian red-spotted dairy breed with silage-haylage type of feeding were selected in the third; and 126 heads of red-spotted breed with silage-haylage-concentrate type of feeding of cows were selected in the fourth farm.

Average samples of feed were taken according to the method generally accepted in zootechnical practice from places of storage of feed – reinforced concrete trenches (pits) with silage and haylage, storage facilities for storing hay and straw, piles with fodder beets, storage facilities for storing skins, mixed feed, etc. Sampling was carried out once in the autumn at

the beginning of the experiment and stall keeping animals. Samples of feeds included in the feeding rations of the animals in the experimental conditions were taken: cereal and bean hay, wheat straw, corn silage, alfalfa haylage, fodder beet, and corn grits in the "Druzhba" agricultural enterprise; alfalfa hay, wheat straw, corn silage, alfalfa haylage, fodder beet, and barley grits in "Khoroshkivsky"; alfalfa hay, cereal hay, corn silage, alfalfa haylage, oatmeal, and peagrass in "Svitanok"; alfalfa hay, cereal and legume hay, corn silage, alfalfa haylage, corn husk and pea husk in "Udai". The samples for the study were sent to the laboratory of the Institute of Animal Husbandry of the Ukrainian Academy of Sciences to establish their nutritional value, the content of macro- and microelements, including heavy metals.

Biochemical analysis of the samples of plant origin (feed) for the content of macro-, microelements, toxic metals, etc. was carried out by the method of atomic absorption spectrophotometry (spectrophotometer AAS-30) (Praice, 1972). The deficiency of macro- and microelements in feed was established relative to the average nutritional value of feed determined in detailed norms (Kalashnikov et al., 1985). The content of Ca, P, Mg, K, S, microelements Fe, Cu, Zn, Co, Mn, J, as well as the concentration of toxic heavy metals Pb and Cd were determined in the average feed samples among macronutrients.

Statistical data processing was carried out in the STATISTICA 10.0 software package for the Windows 7 operating system. The average values of concentrations of mineral elements in 1 kg of feed were determined.

Result

The quality and safety of livestock products, including milk, directly depends on the quality of feed and their biological usefulness. In this regard, in each of the four experimental farms, average samples of feed were taken.

The content of Cd in the feed of the first farm, included in the diet of dairy cows, exceeded the established permissible norms by an average of 2.1–3.2 times, Pb by an average of 2.4–5.7 times, Cu by an average of 1.4–2.3 and Zn by an average of 1.2–2.4 times, respectively. The greatest excess of the norm for Cd and Pb was found in cereal-legume hay (3.2 and 5.7 times), for Cu in corn turf (2.3 times), and for Zn in wheat straw (2.4 times) (Fig. 1).

The concentration of heavy metals in the feed of other experimental farms fluctuated, which was due to the different content of mobile forms of toxicants in the soil and the location of the land where the plants were grown, depending on the distance to the industrial center, highways, natural gas viewing sites, gas condensate enterprises, etc. In the fodder of the second farm, the content of Cd, Pb, Cu, and Zn in excess of the permissible norm was found in fodder beet, respectively, by 2.5, 3.4, 3.8, and 4.1 times. Plants to a greater extent accumulate heavy metals in the root system, that is, in the part that is in the soil, and slightly less pollutants enter the vegetative system; therefore, of all feeds, it was the fodder beet that had the highest level of contamination for all the studied elements in comparison with other feeds (Fig. 2).

In the feed grown on the agricultural lands of the third farm, in addition to exceeding the norm for the

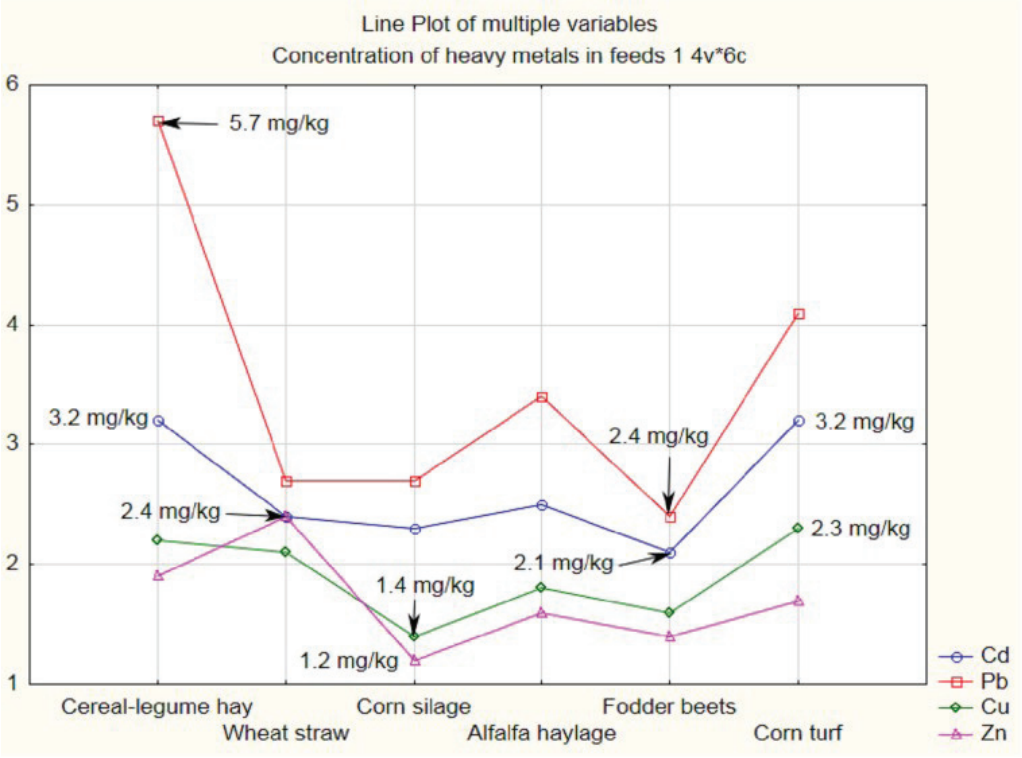

Fig. 1. The concentration of Cd, Pb, Cu and Zn in the feed of the main ration of the first tested farm, mg/kg.

content of Cd, Pb, Cu, and Zn compared with other farms, a high content of zinc was recorded in feed and, in particular, in oat and pea grain on average by 6.3–6.8 times. The highest content of cadmium and lead among other feeds was observed in corn turf, and the highest content of copper was observed in cereal-legume hay (3.9 times) (Fig. 3).

Among all four farms, the fodder of the fourth had the highest contamination of lead by 7.3 times, zinc by 7.8 times and copper by 4.1 times. In terms of feed contamination with cadmium, the farm ranks last along with the second farm. The highest content of cadmium, lead and copper among the ration feeds was found in cereal-legume hay, while corn accumulated more zinc (Fig. 4).

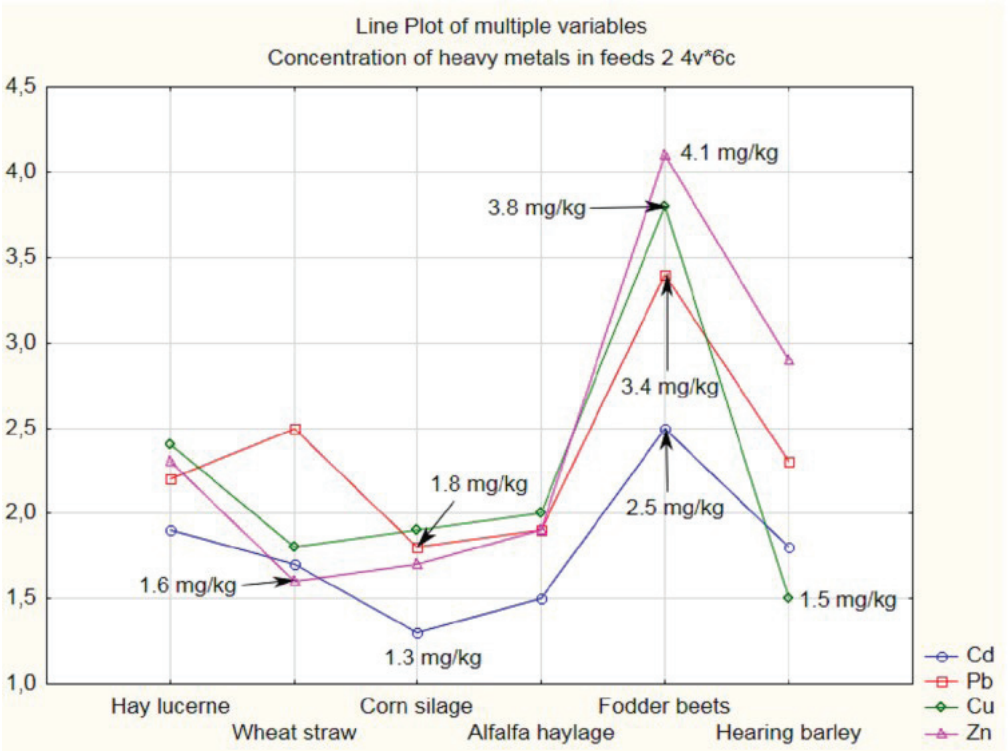

Fig. 2. The concentration of Cd, Pb, Cu and Zn in the feed of the main ration of the second tested farm, mg/kg.

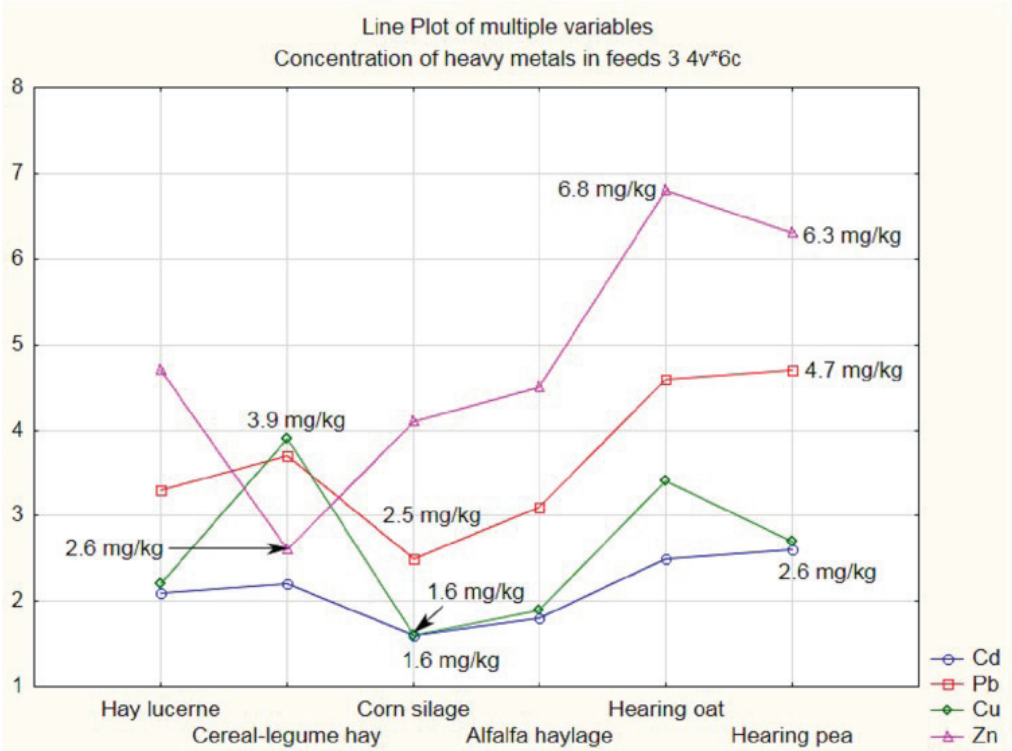

Fig. 3. The concentration of Cd, Pb, Cu and Zn in the feed of the main ration of the third tested farm, mg/kg.

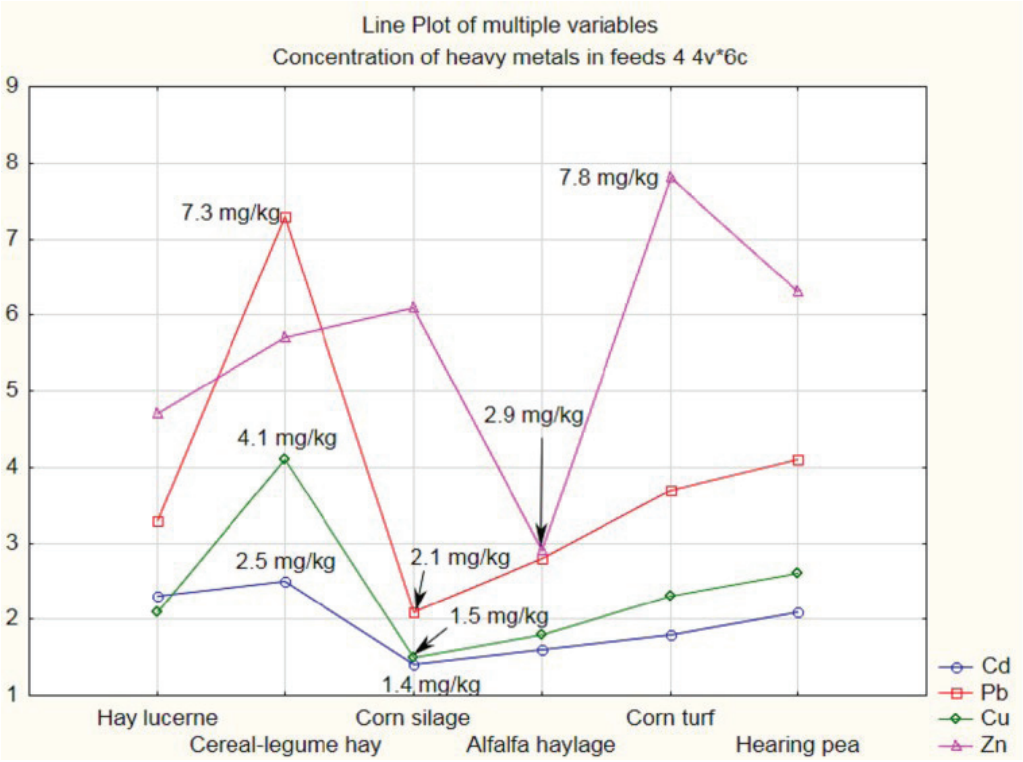

Fig. 4. Concentration of Cd, Pb, Cu and Zn in the feed of the main ration of the fourth tested farm, mg/kg.

Therefore, according to the level of fodder contamination, farms can be ranked as follows: cadmium contamination (in descending order) No. 1 → No. 3 → No. 2 → No. 4; lead contamination (in descending order) No. 4 → No. 1 → No. 3 → No. 2; copper contamination (in descending order) No. 4 → No. 3 → No. 2 → No. 1; zinc contamination (in descending order) No. 4 → No. 3 → No. 2 → No. 1. Copper and zinc are essential elements involved in various biochemical processes vital for the animal organism: hormonal, enzymatic, etc. In a certain amount, they must enter the animal's body. No less important role in the body is played by other essential macro- and microelements, and we carefully studied their content in the feed of farms.

The chemical analysis of the feed shows not only an excess of heavy metals, but also a low content of essential macro- and microelements in plants – antagonists of cadmium, lead, copper and zinc. As evidenced by the results of laboratory analysis of feed for all farms, a low content of essential elements against the background of an excess of heavy metals, especially cadmium and lead, is characteristic. In such conditions, rationing and balancing of rations becomes more difficult.

There is a problem of producing ecologically safe high-quality milk containing heavy metals within the limits of permissible concentrations, as well as containing essential elements important for the human body: calcium, phosphorus, potassium, magnesium, sulfur, iron, iodine, cobalt, vitamins, etc. bringing dairy raw materials into the category of biologically valuable products.

Discussion

Scientists from China (Hui Wang et al., 2013) analyzed a large number of feed and manure samples for heavy metals, collected from 150 livestock farms in Jiangsu Province (China), unlike in our case, where we collected samples from four farms. In the study from China, Zn and Cu concentrations in animal feed were approximately 15.9–2041.8 and 392.1 mg/kg, respectively, while Hg, As, Pb, Cd and Cr in all feeds were below 10 mg/kg. The concentrations of Cu, Zn, and Cr in animal manure were 8.4–1726 mg/kg, 39.5–11 379 mg/kg, and 1.0–1602 mg/kg, respectively, and As, Cd, Hg, and Pb were < 10 mg/kg. The concentration of Cu, Zn, As, and Cr in animal feed and manure demonstrated a positive correlation ($p < 0.001$), but Cd, Hg, and Pb did not statistically correlate with the content in feed and manure. Concentrations of Cu and Zn were highest in pig feed and manure, followed by poultry and lactating animals. During 1990–2008, the content of Cu, Zn, As, Cr, and Cd increased by 771%, 410%, 420%, 220% and 63% in pig manure, by 212%, 95%, 200%, 791% and 63% in dairy animal manure, and by 181%, 197%, 1500%, 261 and 196% in poultry manure. According to scientists, the majority of the increase occurred from 2002 to 2008, indicating the widespread use of feed additives after 2002. In contrast, the levels of Pb and Hg in manure declined steadily from 1990 to 2008. Research results indicate that the content of heavy metals in animal manure has increased significantly over more than 18 years, which will accordingly increase their entry into the soil.

Research on the content of heavy metals in feed is of interest to scientists from different countries and continents of the planet. Scientists (Nicholson et al., 1999) from England examined 183 samples of livestock feed and 85 samples of animal manure collected from commercial farms in England, including Wales. The scientists determined the content of zinc, copper, nickel, lead, cadmium, arsenic, chromium and mercury. Concentrations of zinc and copper in pig feed ranged within 150–2920 mg/kg dry matter for zinc and within 18–217 mg/kg for copper, respectively, depending on the age of the pigs. In poultry feeds, concentrations ranged within 28–4030 mg/kg for zinc and 5–234 mg/kg for copper, while laying hen feeds tended to have higher levels of heavy metals than broiler feeds. Concentrations of Zn and Cu in dairy and meat feeds of cattle were significantly lower than in feeds for pigs and poultry. Pig pus typically contained about 500 mg/kg of zinc and about 360 mg/kg of copper, indicating the metal concentration in the feed. Typical concentrations in poultry manure were 400 mg/kg of zinc and 80 mg/kg of copper, and in cattle manure, there was 180 mg/kg of zinc and 50 mg/kg of copper. The dry matter content of cattle and pig waste has been a useful indicator of the concentration of heavy metals in natural matter.

Scientists from Bashkortostan (Kuramshina et al., 2014) have studied the process of migration of heavy metals from soil to plants (feed) and animals in the area of oil and ore deposits in order to biologically indicate the state of the ecosystem and assess the environmental safety of livestock production in different agricultural areas of Bashkortostan. The authors carefully studied the central part of the republic with the dominant agricultural complex as a background area. Concentrations of elements in soil and forages were determined, coefficients of transition of heavy metals from forages to organisms of animals were established, influence of anthropogenic factors on environmental pollution by heavy metals was estimated. The conclusions made by the scientists in this situation are extremely important from a practical point of view: the more elements entered the environment, polluting agro-ecosystems, plants (feed), the more they were consumed by horses.

Scientists from China (Song Ren-ju et al., 2015) note that feed intake by productive animals plays a key role and has a significant impact on milk yield and milk quality. The researchers have also carried out a laboratory analysis of feed for the content of various mineral elements, including heavy metals, and their transfer into milk of cows. Using similar techniques, in particular, atomic absorption spectrophotometry, they have found the content of Pb, Cd, As, Cu, Mg, Ca, Fe and Zn in different feed and milk. The content of Pb, Cd, and As was determined using an AAS graphite furnace, and the content of Cu, Mg, Ca, Fe, and Zn was determined by flame atomic absorption spectrometry. Research results showed that Pb, Cd, As and Cuwere present in feed, but Pb, Cd and As were poorly detected in milk samples, while Cu was not detected at all. The Mg content in the concentrated feed was lower than in other feeds. However, the Mg content in milk when feeding concentrated feed was higher than when feeding other types of feed, which indicates a more intensive absorption of Mg from the concentrated feed of the diet. The behavior of the concentration of Ca and Zn was opposite to that of Mg. The assimilation of Ca and Zn in the body from other feeds was higher than from concentrated ones. We also observed significant fluctuations in the content of macro- and microelements both in different feeds and in different farms, including milk, which is natural. The problem is that the content of these elements did not correspond to the average nutritional value of feed according to detailed norms of animal feeding. Scientists from China (Song Ren-ju et al., 2015) have not revealed significant changes in the behavior of Fe in the study of feed and milk samples. They come to the conclusion that the relationship between the content of trace elements in feed and milk can become an important theoretical basis for dairy farming, increasing milk yield, improving its quality and milk products. We also agree with that.

Researchers from Peru (Doris Maritza Chirinos-Peinado & Jorge Isaac Castro-Bedriñana, 2020) point to a significant health problem in humans, especially infants, due to the heavy metal content in milk. The concentration levels of lead and cadmium in the blood of animals and the transition of toxic elements into milk of cows in rural areas near the metallurgical complex in Peru (La Oroya Metallurgical Complex in Peru), which has been emitting into the air for more than 90 years, have been investigated and evaluated. The samples were analyzed in the same way as in our research (Mamenko & Portiannik, 2019; Mamenko & Portiannik, 2021). The results of the analysis showed that the levels of Pb in blood and milk in mg/kg were 0.38 ± 0.041 and 0.58 ± 0.018, respectively; the Pb level in milk was 54% higher than in blood ($p < 0.01$). The concentration of Cd, in mg/kg, in blood and milk was 0.016 ± 0.002 and 0.02 ± 0.007, respectively; milk contained 28% more Cd than blood ($p < 0.05$). The results of the Pb content in milk were compared with the Codex Alimentarius standard (0.002 mg/kg); the average concentration of the element in milk was 29 times higher than the permissible norm, and the average concentration of Cd was 2 times higher than the permissible norm of the Romanian standard (0.01 mg/kg). The scientists explain the result by the influence of environmental pollution by waste products of the enterprise. In the state standard for milk in Ukraine, the norm for cadmium is 0.03 mg/L, and for dairy raw materials used for the production of baby food, it is 0.02 mg; for lead, respectively, 0.1 mg/L and 0.05 mg/L. The Romanian standard is more stringent in terms of milk safety than the Ukrainian one. In Peru, as

the scientists note, there are no norms for maximum values of Pb and Cd at all, so the researchers propose to establish the norms for the maximum permissible concentration of these elements in cow's milk. Ukrainian scientists (Slivinska et al., 2021) have also conducted research in conditions of increased man-made pollution of the Lvov-Volyn coal basin on dairy cows of black-and-white breed from the influence of toxic metals cadmium and lead on the physiological state of animals. As a result, it was found that protein metabolism in cows from the contaminated area was characterized by hypoproteinemia (32.5% of cows), hypoalbuminemia (30%), hypogammaglobulinemia; 77.5% of cows increased the activity of aspartate aminotransferase and 66.5% increased the activity of alanine aminotransferase. The concentration of urea and creatinine increased in the serum of cows, depending on the distance of keeping animals 3–5 km from the mines. It is obvious that the intoxication of the cows' organisms occurred both as a result of the consumption of feed containing heavy metals, and as a result of their intake from the atmospheric air.

All these studies by scientists from around the world indicate that pollution of the environment with heavy metals leads to their accumulation in plants (feed), which are used in animal feeding and then enter milk or simply accumulate in various organs and tissues, which can have a negative impact on the health of people consuming the product. Therefore, it is important to constantly monitor the pollution of ecosystems with heavy metals, environmental control of polluting sectors of the economy in different countries of the world, including Ukraine, the development of new more effective technological methods for the production of ecologically safe high-quality milk, or their improvement.

Conclusion

In conditions of local pollution of agroecosystems with heavy metals, it is unacceptable to balance rations without taking into account the concentration of pollutants, especially toxic heavy metals such as cadmium and lead in feed, and also without taking into account the actual nutritional value of feed. The production of ecologically safe cow's milk in such farms is a technologically very difficult task and it will be impossible to solve the problem without rationing these mineral elements in the diet or using special antidotes in the form of mineral and vitamin premixes of other feed additives. Food, as an environmental factor, will lead to disruption of the homeostasis of the organism of a productive animal, which can lead to a decrease in productivity and deterioration of health.

Further research is aimed at environmental monitoring of the content of toxic metals and various essential and non-essential mineral elements in feed for productive animals in different regions of Ukraine, forest-steppe and Polissya.

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