Application of Effective Technological Methods for the Production of Environmentally Safe Cow's Milk

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Abstract. *The production of crop and livestock products in agro-ecosystems requires not only systematic monitoring of quality and environmental safety, but also the development of effective technological methods for the production of environmentally safe cow's milk. The purpose of the research is to analyze the effectiveness of the applied technological methods in feeding productive cows for the production of environmentally safe milk and increasing animal productivity. Experiments were conducted on dairy cows of the Ukrainian black and red-motley dairy breeds with different types of feeding: silage-root, silage-hay, silage-haylage, and silage-hay-concentrate. The main diet of cows was supplemented with a specially developed mineral-vitamin premix, taking into account the antagonistic effect of its components on the ecotoxicants lead (Pb) and cadmium (Cd). The animals of the control group were on the main diet, while the second and third groups additionally ate the premix. The average daily milk yield was 14.0–14.8 kg. Laboratory chemical analysis of average feed samples for the concentration of macro- and microelements, including Pb and Cd, was carried out by the atomic absorption method. The STATISTICA version 10.0 program was used for statistical processing of the results obtained. Chemical analysis of feed showed an increased content of heavy metals lead, cadmium, copper, and zinc. Analysis of diets showed a deficiency of macro- and microelements in cobalt (64.5%), iodine (59.8%), phosphorus (43.1%), sulfur (33.5%), calcium (7.6%), and magnesium (7.2%) in cows with silage-root type of feeding; deficiency of cobalt (54.1%), phosphorus (47.4%), iodine (40.1%), sulfur (28.0%), manganese (2.3%) in silage-hay feeding; deficiency of cobalt (80.7%), iodine (65.2%), phosphorus (56.7%), sulfur (5.5%) in silage-hay feeding; and deficiency of cobalt (79.83%), iodine (20.15%), phosphorus (50.91%), sulfur (25.15%), manganese (20.15%), magnesium (2.7%) in silage-hay-concentrate feeding. Cobalt (54.1–80.7% average percentage of deficiency), phosphorus (43.1–56.7%), iodine (20.15–65.2%), sulfur (5.5–33.5%), manganese (2.3–20.15%), magnesium (2.7–7.2%) and calcium (7.6%) were the most deficient in all diets. The deficiency of these essential elements increases the toxic effects of Pb and Cd. Feeding a mineral-vitamin premix contributed to a lower incorporation of heavy metals in the body of animals of the experimental groups, which positively affected their physiological state and productivity, which increased on average by 1.3–1.7 times compared with animals of the control groups ($P < 0.001$). The silage-hay type of feeding was the most effective in relation to feeding the premix in the second experimental group. The milk productivity of cows increased by 1.6 times compared with the control group ($P < 0.001$). In cows with a silage-root crop type of feeding, productivity increased by 1.3 times, in cows with silage-hay-concentrate by 1.3 times, in cows with silage-haylage by 1.4 times, and in cows with silage-hay by 1.6 times, respectively. Balancing the main diet with an antitoxic premix contributed to a slight increase in milk production from 3477–4426 kg per lactation in the first control groups to 5444–5999 kg per lactation in the second experimental groups. Subcutaneous injection of a plant biopreparation enhanced the antitoxic effect of the premix, which also had a positive effect on the productivity of cows in the third experimental groups, where productivity increased by an average of 1.3–1.7 times. Among cows in the third experimental groups, the silage-hay type of feeding proved to be the best, milk productivity increased by 1.7 times compared with the control group ($P < 0.001$). The production of environmentally safe milk in areas of local contamination with heavy metals of technogenic, military origin requires the use of new proven technological techniques with feeding in rations of various types of special premixes, which allows for maximum balance of feeding, restoration of homeostasis of the organism in which heavy metals are incorporated, and increased cow productivity and milk production.*

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Introduction

Russia's aggression against Ukraine has significantly complicated the environmental security situation not only in agriculture, but also in the country as a whole. Shelling of the Ukrainian infrastructure by "Shaheds", mining, rocket attacks, undermining of the power plant dam, shelling of the Chernobyl nuclear power plant zone, etc. are turning into a global problem, due to the emergence of a humanitarian catastrophe from hostilities. There is a threat of biological, chemical, nuclear disasters, etc. (Kovaleva, 2025; Nayd′onova, 2023).

Hazardous pollutants and xenobiotics, including heavy metals such as cadmium and lead, cause local pollution around developed industrial centers. The accumulation of ecotoxicants in soil, plants (animal feed), even in small concentrations, is primarily caused by man-made sources. Highways with a large number of mobile vehicles, the vast majority of which have gasoline engines, pollute the soil with lead. Heavy metals enter the environment in significant quantities with emissions from stationary sources like enterprises. A significant anthropogenic and man-made impact is exerted by enterprises of the oil and gas industry complex, especially if they suffer man-made accidents or are hit during shelling by an aggressor. In war conditions, the combustion of rocket fuel during shelling of the territory, the flight of drones with internal combustion engines, etc. also causes atmospheric air pollution with toxic heavy metals, oxides of nitrogen, sulfur and carbon, including the impact on the development of the greenhouse effect. Pollutants settle on the soil surface and migrate in trophic chains, entering the body of dairy cows with feed. Intensive use of pesticides and mineral fertilizers increases the accumulation of heavy metals in the soil, their transfer to plants, disrupting the micro- and macroelement composition of animal feed in various soil and climatic zones of Ukraine, including Forest-Steppe, Polissya.

Analysis of the environmental situation in Ukraine shows that environmental pollution by heavy metals has increased over the past decades. The situation was especially complicated during the war. According to forecasts, the state of the environment and agroecosystems will be difficult in the post-war period (Kushnir and Onipko, 2018). Soil contamination with heavy metals can cause potential environmental risks, crop losses and human health risks (Mingtao Xiang et al., 2021).

The adverse impact on agrobiogeocenoses located around developed industrial centers, including the effect of intensive traditional farming, is increasing in different countries of the world. Phosphate mineral fertilizers, which are applied to the soil to increase crop yields, contain trace elements, including heavy metals, which are potentially dangerous to humans and the environment (Kratz et al., 2016). Providing crops with the necessary macro- and micronutrients is the main goal of any type of fertilizer. However, micronutrients can become harmful when present in high concentrations. In Germany, the content of undesirable elements in fertilizers is regulated by the German Fertilizer Ordinance, which sets limit values for cadmium, arsenic, mercury, chromium, and lead. Copper and zinc are considered essential elements and are therefore no longer regulated (Kratz et al., 2016). Frequent use of phosphate fertilizers can lead to the accumulation of heavy metals and undesirable concentrations in agricultural soils and subsequently in plants. There is particular concern about the accumulation of cadmium and uranium, as these metals are toxic and can threaten soil fertility, leach into groundwater and be absorbed by crops (Bigalke et al., 2017).

Once in the soil, heavy metals accumulate to harmful concentrations undesirable for agricultural plants, especially those used as feed in animal diets of any type of feeding. Soil fertility can also be negatively affected. The transfer of toxic heavy metals such as cadmium and lead from the soil to plants, and then to the body of productive animals can complicate the production of high-quality environmentally safe cow's milk (Vardhan et al., 2019; Portiannyk and Mamenko, 2021).

The entry of cadmium and lead into the body of animals causes cumulative toxicity, negative effects on internal organs and systems (Hashemi, 2018). Animal productivity decreases (Goff, 2018). The accumulation of pollutants in soil and feed significantly increases the risk of incorporation into the body of dairy cows, which threatens the health of animals and, through contaminated milk, humans themselves (Hashemi, 2018; Rezza et al., 2018). Chronic cadmium intoxication leads to nephrotoxicity, hepatotoxicity, immunotoxicity, osteotoxicity, oxidative stress of liver and kidney cells, damage to deoxyribonucleic acid, carcinogenesis, and cancer (Liu et al., 2009).

Today there is a need to develop new technological methods in feeding and production of environmentally safe livestock products if the rations contain toxic heavy metals. Monitoring the intake of mineral elements with feed into the body of animals and their accumulation in livestock products is of great importance (Hejna et al., 2018). Research into the relationship between the concentration of trace elements in feed and milk is an important basis for effective environmentally safe dairy farming, which contributes to increasing animal productivity, improving the quality and environmental safety of the milk produced (Ren-ju et al., 2015).

The purpose of the research is to analyze the effectiveness of technological methods used in feeding high-yielding cows to produce environmentally safe milk and increase animal productivity.

Materials and methods

Scientific and economic experiments were conducted in the farms of the Forest-Steppe zone of Ukraine. The experiment was conducted on dairy cows of Ukrainian black and red-motley dairy breeds in the third lactation period. Rations with different types of feeding were used: silage-root, silage-hay, silage-haylage, silage-hay-concentrate. Animals of the first control group were fed the main ration. The second and the third groups, in addition to the main ration, a specially developed mineral and vitamin premix MP-A, were fed with the content of elements of toxicant antagonists and elements that, under conditions of intoxication, compensate for the lack of essential elements in the body: selenium, sulfur, magnesium, manganese, phosphorus, cobalt, iron, iodine, as well as methionine – an amino acid containing a ligand sulfhydryl group, vitamins A, D, E, PP, C, H, B2, etc. In the third experimental group of cows with different types of feeding, a subcutaneous injection of a biological preparation from the extract of medicinal plants BP-9 was used to enhance the antitoxic effect of the premix.

The average live weight of the cows was 500–545 kg. The average daily productivity was 14.0–14.8 kg. The milk production of animals was recorded based on ten-year control milk yields. The comparative period was 42 days, and the experimental period was one 120 days (Table 1). All manipulations with animals were carried out in accordance with the European Convention for the Protection of Vertebrate Animals Used for Experimental and Scientific Purposes (Strasbourg, 1986).

Feeding the premix at the rate of 1% of the ration

Table 1. Scheme of scientific and economic experiments

Animal groups	Number of goals in the group	Average live weight at the beginning of the experiment, kg, ±5–10%	Age, months, at the beginning of the study	Duration of the experiment, days	Feeding type	Feeding characteristics
Comparative period						
Control group 1	12 – 1 65 – 2 21 – 3 42 – 4	500	64	42	Silage-root crops – 1 Silage-hay – 2 Silage-haylage – 3 Silage-haylage-concentrate – 4	The main diet balanced in terms of feed units, digestible protein, etc. indicators. The composition includes the following feeds: alfalfa hay (2, 3, 4), cereal-legume (1, 3, 4), wheat straw (1, 2), corn silage (1–4), alfalfa haylage (1–4), fodder beet (1, 2), corn grits (1, 4), barley (2), oat (3) and pea (3, 4), which exceed the maximum permissible concentration for Cd, Pb, Cu, Zn.
Experi-mental group 2	the same	500	64	42		the same
Experi-mental group 3	the same	500	64	42		the same
Experimental period						
Control group 1	the same	500	65	120	same	the same
Experi-mental group 2	the same	500	65	120		Basic ration + developed premix. MP-A-1, MP-A-2, MP-A-3, MP-A-4
Experi-mental group 3	the same	500	65	120		Basic diet + developed premix + drug BP-9

Note:
1 – experiment with Ukrainian black-mottled dairy breed of cows with silage-root crops type of feeding;
2 – experiment with Ukrainian black-mottled dairy breed of cows with silage-hay type of feeding;
3 – experiment with Ukrainian red-mottled dairy breed of cows with silage-haylage type of feeding;
4 – experiment with Ukrainian red-mottled dairy breed of cows with silage-haylage-concentrate type of feeding.

was as follows: cows with silage-root and silage-hay feeding type received 250 g per head per day; cows with silage-hay-concentrate feeding received 290 g; cows with silage-haylage feeding received 255 g. The recipe (formula) of the premix MP-A and the plant biopreparation BP-9, the methodology for developing the mineral-vitamin premix MP-A adapted to the actual daily feeding rations belongs to the authors of this publication Mamenko and Portiannyk (Ukraine).

Agricultural lands of farms are located near environmentally harmful man-made objects of influence on agrobiogeocenoses, highways with increased traffic of vehicles, such as Kyiv, Kharkiv, Dovzhansky routes, main oil and gas pipelines, etc. Average feed samples (n = 6) were selected according to the generally accepted method in zootechnical practice from feed storage areas, reinforced concrete pits with silos, haylage, storage facilities for storing hay, straw, haystacks with fodder beets, warehouses for storing concentrated feed, mixed feeds, etc.

Laboratory chemical analysis of plant samples for the content of macroelements Ca, P, Mg, K, S, and microelements Fe, Cu, Zn, Mn, J, Pb, Cd was carried out by atomic absorption spectrophotometry (AAS-30 spectrophotometer). The deficiency of macro- and microelements in feed was established relative to the average nutritional value of feed specified in detailed standards (Kalashnikov et al., 1985).

The material for analyzing the relevance of the problem and discussing it included scientific review and research articles from international scientific sources that are in open access on Scopus and Web of Science Core Collection databases.

Ecological monitoring of the Forest-Steppe zone of Ukraine is carried out by scientists regularly in accordance with the stages of R&D implementation. State registration number: 0121U113933 dated November 18, 2021 (Fig. 1).

For each sample, the mean value of the trait in the sample (M) and the standard deviation (SD) were calculated. The estimate is given in the form of M ± SD. Differences between the mean values were considered statistically significant at $P < 0.05$. The calculation was performed in the STATISTICA software package version 10.0.

Results

The determining role belongs to the factor of feeding and mineral-organic nutrition of dairy cows in reducing the load of their body with heavy metals, especially cadmium and lead. To develop a special mineral-vitamin premix of the MP-A type, which was used in feeding cows of the second and third experimental groups, a deep analysis of one of the main factors in such ecological situations, i.e., feeding, was carried out.

The quality of feed is determined by the type of plants, their botanical composition, the vegetation phase, climatic conditions, including the influence of abiotic and anthropogenic factors, agricultural techniques for crop cultivation and storage conditions. For laboratory analysis, we selected average samples of feed that were used to feed the experimental groups of cows. In addition, we selected average samples of those feeds that could be used in feeding when creating optimal types of feeding in terms of heavy metal contamination. The feed that was part of the rations and fed to the cows was of good quality. Hay and straw had a pleasant smell and their own color. In silage, crushed plant particles retained their structure and consistency, the leaves were elastic and easily separated from each other, the smell was pleasant, specific. Hay also had a pleasant smell, a characteristic consistency and was of good quality. Concentrated feed had a glossy surface, a characteristic shine, color and sweetish-fresh taste. Silage and hay were prepared in above-ground reinforced concrete silage-hay trenches, hay and straw in slats and bales, and concentrated feed was stored in a warehouse.

Against the background of good quality feed, the content of heavy metals in them, in particular cadmium, lead, copper and zinc in concentrations exceeding the maximum permissible norms, indicates their high hidden danger, since it is impossible to visually determine the content of xenobiotics, as well as radioactive substances, in feed. The amount of cadmium in the diet of animals with silage-root type of feeding exceeded the norm by an average of 2.1–3.2 times, lead exceeded the norm by 2.4–5.7 times, copper by 1.4–2.3 and zinc by 1.2–2.4 times (Figs. 2–5). A comparison of established concentrations of heavy metals in feed was carried out following the mandatory minimum list of studies of raw materials, products of animal and plant origin, feed raw materials, feed, vitamin preparations, etc. that should be conducted in state laboratories of

Registration card for research and development work

State Registration Number: 0121U113933 **Public**

Date of Registration: 18-11-2021

Status of the performer: 17 - Chief Executor

Fig. 1. Registration card for research and development work
Source: Ukrainian Institute of Scientific and Technical Expertise and Information (n.d.)

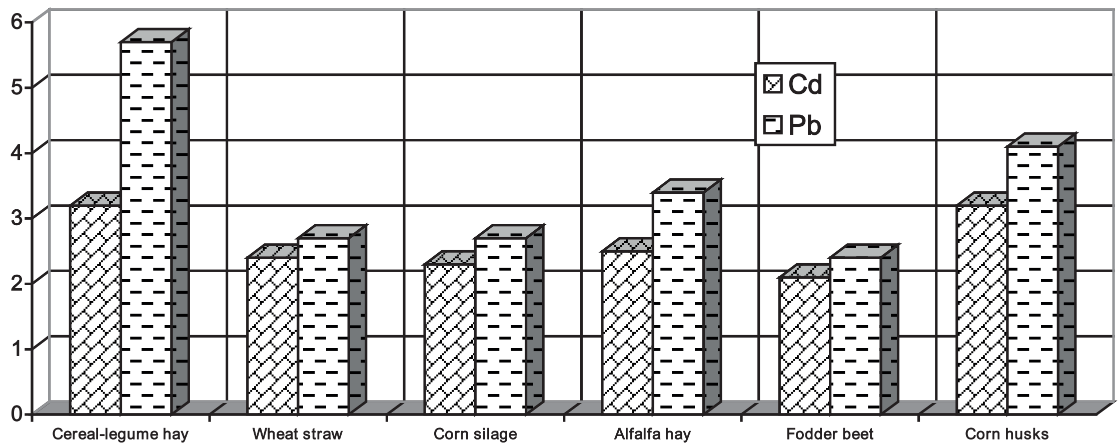

Fig. 2. Cd and Pb content in silage-root crops type feed of the main ration, mg/kg (source: developed by the authors).

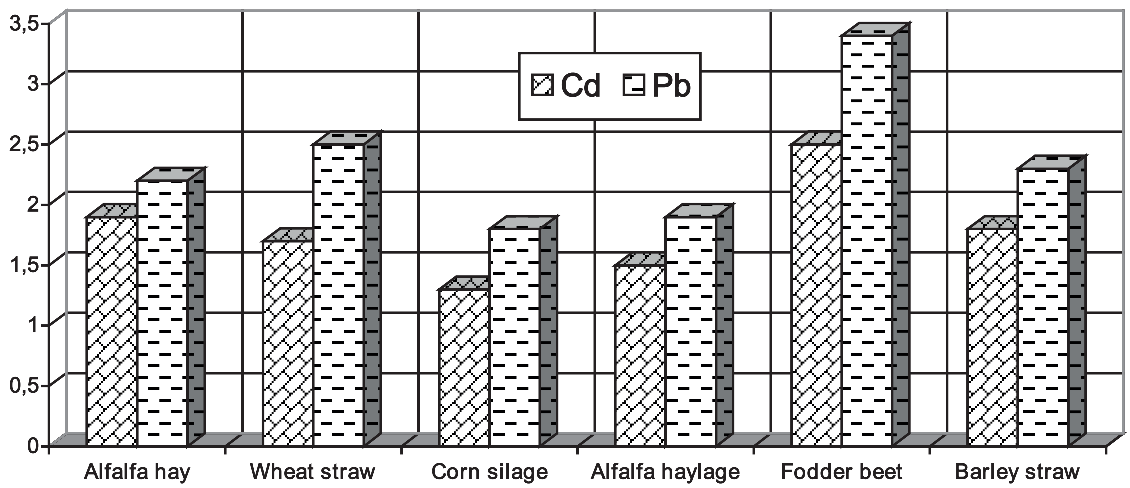

Fig. 3 Cd and Pb content in the main silage-hay type feed, mg/kg (source: developed by the authors).

veterinary medicine and based on the results of which a veterinary certificate (F-2) is issued (State Department of Veterinary Medicine, 1998).

Cereal-legume hay had the highest excess of the permissible concentration for cadmium and lead exceeding the norm by 3.2 and 5.7 times, corn stalks had the highest concentration of copper exceeding the norm by 2.3 times, and wheat straw had the highest zinc content, which exceeded the permissible norm by 2.4 times. The concentration of heavy metals in the diets of dairy cows with other types of feeding fluctuated. There are many reasons for that. Different farms used different amounts of mineral fertilizers and pesticides, which affected the different concentration of mobile forms of pollutants in the soil, the distance of agricultural lands where fodder crops were grown from sources of technogenic influence, etc., but in the feed of dairy cows with silage-hay type of feeding, the highest concentration of cadmium, lead, copper and zinc was found in fodder beets exceeding the norm by 2.5 times, 3.4 times, 3.8 times, and 4.1 times, respectively. Fodder beets had the highest level of all studied elements compared with other feed types. Where cows were fed a silage-hay diet, compared with other experiments, a high concentration of zinc in oat grain and peas was found exceeding the norm on average 6.3–6.8 times, while an excess of the permissible norm of cadmium, lead, cuprum and zinc was also observed.

Pea grits among other feeds differed in the highest concentration of Cd, Pb, and Cu in cereal-legume hay, where the level recorded exceeded the norm by 3.9 times. Feed of the diet of animals with a silage-hay-concentrate type of feeding demonstrated the highest excess of the norm of Pb by 7.3 times, Zn by 7.8 times, and Cu by 4.1 times. In terms of the content of Cd in feeds, this diet ranks last together with the diet of a silage-hay type of feeding of dairy cows. Among other feed types in the diet, cereal-legume hay accumulated the most cadmium, lead, and copper. Corn grain accumulated the most zinc.

The main diet of the experimental groups of cows for different types of feeding was compiled according to the nutritional value of the feed, which was established after laboratory analysis, taking into account the content of the studied Cd, Pb, Cu, and Zn. In the main diet of experimental cows with silage-root, silage-hay, silage-haylage and silage-hay-concentrate feeding, the number of feed units and metabolizable energy was maximally balanced. Crude

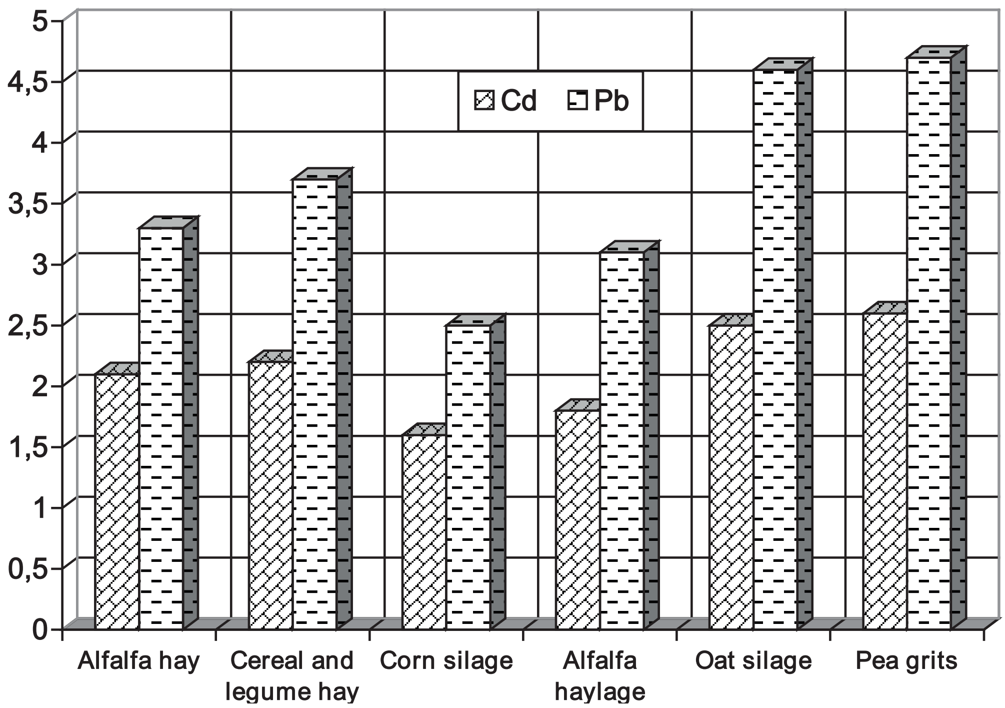

Fig. 4. Cd and Pb content in the main silage-haylage feed ration, mg/kg (source: developed by the authors).

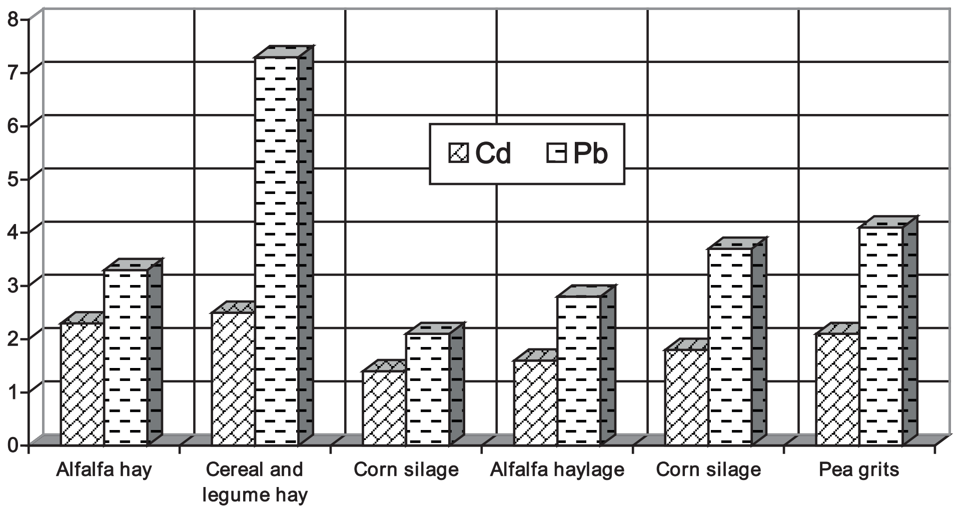

Fig. 5. Cd and Pb content in the main ration of silage-haylage-concentrate type feed, mg/kg (source: developed by the authors).

fiber, crude and digestible protein were balanced in the diet of cows with silage-root crops, silage-hay and silage-haylage feeding type.

In the diet of cows with silage-hay-concentrate feeding, it was not possible to balance the rations due to the set of feeds; therefore, the deficit of crude protein was 7.03% and that of crude fiber was 12.66%. It is important that the content of digestible protein was within normal limits. The sugar-protein ratio was within normal limits in all diets. The content of crude fat was also within normal limits.

At the same time, a low dry matter content was observed in the diet of animals with silage-root crop feeding (15.1%), silage-hay (17.9%) and silage-hay-concentrate (3.62%). Only in the diet of cows with silage-hay type of feeding this deficiency was not observed, which is to some extent due to the type of feeding, and only the silage-hay type diet did not have a dry matter deficiency. In addition, in the diet of cows with silage-root crop feeding, silage-hay and silage-haylage, a starch deficiency of 26.5%, 32.9%, and 17.4% was observed, respectively. In the diet of animals with silage-hay-concentrate type of feeding, the starch content was within normal limits. Among macro- and microelements in the diet of cows with silage-root type of feeding, the greatest deficiency was in cobalt (64.5%), iodine (59.8%), phosphorus (43.1%), sulfur (33.5%), calcium (7.6%), and magnesium (7.2%); in the diet of cows with silage-hay type of feeding, the deficiency was in cobalt (54.1%), phosphorus (47.4%), iodine (40.1%), sulfur (28.0%), and manganese (2.3%); in the diet of cows with silage-haylage, the deficiency was in cobalt (80.7%), iodine (65.2%), phosphorus (56.7%), and sulfur (5.5%); and in the diet of cows with silage-hay-concentrate, it was in cobalt (79.83%), iodine (20.15%), phosphorus (50.91%), sulfur (25.15%), manganese (20.15%), and magnesium (2.7%). As we can see, the most deficient elements in all diets were as follows (in descending order of %): cobalt (54.1–80.7% average percentage of deficiency), phosphorus (43.1–56.7%), iodine (20.15–65.2%), sulfur (5.5–33.5%), manganese (2.3–20.15%), magnesium (2.7–7.2%) and calcium (7.6%).

The basic diet of dairy cows in all four experimental farms can be considered balanced in terms of basic indicators such as feed units, metabolizable energy, crude and digestible protein, crude fiber, crude fat, sugar, as well as macro- and microelements of potassium, iron, and, in some diets, calcium, magnesium, and manganese. The diets had an optimal sugar–protein ratio of 0.8–1.1, a sugar–starch ratio of 0.6–1.2, and a calcium–phosphorus ratio of 2.31:1 in animals fed silage-root crops, 4.7:1 in silage-hay, 7.4:1 in silage-haylage, and 5.6:1 in silage-hay-concentrate, which is due to the low phosphorus content in the feed, since cadmium and lead can reduce its entry into the plant from the soil.

Thus, the developed basic diets for dairy cows in all experimental farms, while being balanced in the main most important indicators, did not contribute to a decrease in the absorption of heavy metals into the blood and an increase in milk productivity of animals in the first control groups (Table 2).

Tables 3–6 show the descriptive statistics. The calculation includes the arithmetic mean, median with lower and upper quartiles, maximum and minimum average daily milk yield for each experimental group. At the same time, a slight difference was found between the arithmetic mean and median. The STATISTICA program allowed for the most accurate data analysis and description of the average daily animal productivity obtained as a result of the research.

As can be seen from Tables 2–6, the productivity of cows in the first control group fed the main diet had lower productivity compared with animals in the second and third experimental groups fed a specially developed mineral-vitamin premix ($P < 0.001$). The lowest milk productivity among cows in the control group was in animals fed silage-hay type of feeding at 11.40 ± 0.61 kg, followed by a slightly higher productivity in animals in the control group fed silage-hay type of feeding (14.04 ± 0.61 kg), in cows fed silage-root (14.31 ± 0.74 kg) and in cows fed silage-hay-concentrate (14.51 ± 0.67 kg).

The use of a technological method in the experiment, which involved feeding animals of the second and third experimental groups a special premix MP-A developed according to the method by Portiannyk and Mamenko, improved the situation

Table 2. Milk production of cows (M ± SD)

Indicators	Animal feeding type											
	Silage-root crops			Silage-hay			Silage-haylage			Silage-haylage-concentrate		
	Control group 1	Experimental group 2	Experimental group 3	Control group 1	Experimental group 2	Experimental group 3	Control group 1	Experimental group 2	Experimental group 3	Control group 1	Experimental group 2	Experimental group 3
Average daily milk yield, kg	14.31 ± 0.74	17.85 ± 0.89	18.68 ± 1.03	11.40 ± 0.61	18.41 ± 0.70	19.62 ± 1.11	14.04 ± 0.61	19.67 ± 0.84	21.65 ± 0.73	14.51 ± 0.67	19.33 ± 0.92	22.62 ± 0.70

Notes: degree of probability compared with the data of the control group $P < 0.001$; n = 12.
Source: developed by the authors

Table 3. Descriptive statistics of average daily milk yield of experimental cows with silage-root crops type of feeding, n = 12

Animal groups	% Valid obs.	Mean	Median	Sum	Minimum	Maximum	Lower Quartile	Upper Quartile	Standard Deviation	Standard Error
Control group 1	33.33333	14.31083	14.27000	171.7300	13.52000	15.38000	13.60000	15.14500	0.739367	0.213437
Experimental group 2	33.33333	17.85250	17.61000	214.2300	16.79000	19.57000	17.28000	18.49000	0.886414	0.255886
Experimental group 3	33.33333	18.68333	18.39500	224.2000	17.41000	21.02000	18.13500	19.07500	1.027675	0.296664

Source: developed by the author

Table 4. Descriptive statistics of average daily milk yield of experimental cows with silage-hay feeding, n = 12

Animal groups	% Valid obs.	Mean	Median	Sum	Minimum	Maximum	Lower Quartile	Upper Quartile	Standard Deviation	Standard Error
Control group 1	33.33333	11.40083	11.40500	136.8100	10.42000	12.42000	10.88000	11.72000	0.611116	0.176414
Experimental group 2	33.33333	18.41167	18.12500	220.9400	17.75000	20.21000	18.06000	18.61500	0.701218	0.202424
Experimental group 3	33.33333	19.62083	19.22000	235.4500	18.18000	22.02000	19.14500	20.18000	1.109344	0.320240

Source: developed by the authors

Table 5. Descriptive statistics of average daily milk yield of experimental cows with silage-haylage feeding type, n = 12

Animal groups	% Valid obs.	Mean	Median	Sum	Minimum	Maximum	Lower Quartile	Upper Quartile	Standard Deviation	Standard Error
Control group 1	33.33333	14.04417	13.91000	168.5300	13.27000	15.59000	13.69500	14.29500	0.609835	0.176044
Experimental group 2	33.33333	19.67417	19.38000	236.0900	18.31000	21.14000	19.20500	20.18500	0.840146	0.242529
Experimental group 3	33.33333	21.65000	21.52000	259.8000	20.36000	23.06000	21.40000	22.13000	0.730790	0.210961

Source: developed by the authors.

Table 6. Descriptive statistics of average daily milk yield of experimental cows with silage-haylage-concentrate feeding type, n = 12

Animal groups	% Valid obs.	Mean	Median	Sum	Minimum	Maximum	Lower Quartile	Upper Quartile	Standard Deviation	Standard Error
Control group 1	33.33333	14.51417	14.49500	174.1700	12.92000	15.23000	14.30500	15.15000	0.668192	0.192891
Experimental group 2	33.33333	19.33250	19.32500	231.9900	17.82000	21.71000	18.94000	19.53500	0.916070	0.264447
Experimental group 3	33.33333	22.62250	22.52500	271.4700	21.36000	24.17000	22.30500	22.84500	0.695494	0.200772

Source: developed by the authors.

with the quality and environmental safety of milk. The milk productivity of animals under different types of feeding slightly increased compared with animals of the control groups ($P < 0.001$). The premix recipe ensured the normalization of the content of heavy metals in the diets of dairy cows with different types of feeding, taking into account the antagonistic, synergistic and adaptive effects of its components. The production of the premix is not complicated and is available to any farm if necessary.

Therefore, thanks to the proven technological method of balancing rations with a special mineral-vitamin premix, we managed not only to reduce the burden of heavy metals on the body of productive animals, to support the healthy functioning of important organs and systems of the body due to the essential, biogenically important mineral elements and vitamins introduced into the premix, but also to slightly increase milk productivity up to 6 thousand kilograms per lactation, which makes this method economically effective and environmentally appropriate, since the milk produced was environmentally safe and met both domestic and international quality standards.

Discussion

We completely agree with other researchers (Renju et al., 2015) that feed consumption plays a decisive role in influencing the milk production of cows as well as the quality and environmental safety of the milk produced. Ren-ju et al. (2015) also investigated the content of trace elements, including heavy metals, in cow's milk under the influence of various feeds. The researchers determined the concentration of lead, cadmium, arsenic, copper, magnesium, calcium, iron and zinc in various feeds and milk using a method similar to ours – the method of atomic absorption spectrophotometry. The determination of the content of lead, cadmium and arsenic was carried out using AAS in a graphite furnace, while the content of copper, magnesium, calcium, iron and zinc was determined using flame atomic absorption spectrometry. The results showed that lead, cadmium, arsenic and copper were present in feeds, but lead, cadmium and arsenic were weakly detected in milk samples, and copper was not detected at all in milk samples. The content of magnesium in concentrated feeds was lower than in other types of feeds (Song Ren-ju et al., 2015). Magnesium deficiency in feed under the conditions of our experiment caused a deficiency of the element in the diet of cows with silage-root type at the level of 7.2%, and with silage-hay-concentrate type at 2.7%. In general, in all diets, magnesium was the most deficient (2.7–7.2%), which is to some extent consistent with other studies (Ren-ju et al., 2015). It has also been found that there was more magnesium in the milk of animals that consumed more concentrated feeds than forage (Ren-ju et al., 2015). This indicates that the use of magnesium in concentrated feeds was higher than in forage. The content of calcium and zinc was the opposite of magnesium, and the use of calcium and zinc in forage feeds was higher than in concentrated feeds. The researchers did not establish patterns of changes in iron in different feeds and milk samples. We agree with the opinion of Ren-ju et al. (2015) that the ratio between the content of trace elements, including metals, in milk and feed will become the theoretical basis for dairy farming, which is very important for increasing milk yields, quality and environmental safety of milk in dairy production.

The deficiency of these essential elements only enhances the toxic effects of Cd and Pb. Since some elements, such as cobalt and sulfur, are antagonists of heavy metals, other elements – calcium, phosphorus, iodine, manganese, magnesium – support the normal functioning of organs and systems important for the body of productive cows, which are affected by heavy metals and perform a protective function of the body. The lack of these rather important biochemically active elements in the diet, in our opinion, is due not to different feeding styles of cows, but to the low intake of these elements from the soil into animal feed with an increased content in the soil of such dangerous toxicants as Cd, Pb, Cu, Zn. These xenobiotics affected the reduction of the transition of vital biogenic essential elements from the soil to plants. Due to their high biological activity in the form of various salts of sulfates, nitrates, chlorides, etc. in high concentrations they migrated to plants that were included in the feeding rations as feed. This is the main reason that should beware zootechnical specialists who are directly involved in the development of diets for dairy cows and milk production in conditions of local contamination of agroecosystems with heavy metals Cd, Pb, Cu, and Zn near developed industrial centers. The content of such biogenic elements as potassium, iron, and in some diets, manganese, magnesium and calcium was in sufficient quantities, but against this background, the content of heavy metals Cd, Pb, Cu, Zn exceeded the physiological norm. The intake of carotene corresponded to the norm in the diets of all farms, as well as the content of vitamins D and E.

Other scientists (Tao et al., 2020) emphasize that environmental pollution with heavy metals threa-tens the health and life of animals and humans due to their migration through the food chain, and we also agree with this. Chinese scientists took feed samples in the same way as we did in our study, analyzing them for the content of cadmium, mercury, chromium, and arsenic using the method of atomic absorption spectrophotometry or atomic fluorescence spectrometry for analysis. Researchers found high levels of contamination with feed pollutants in Hubei province. They emphasize the importance of monitoring the content of heavy metals and point to the implementation of a feed management strategy, conducting boron mediation to reduce the impact of pollutants.

If the feed contains trace elements of heavy metals, especially such as lead and cadmium, in high concentrations this causes their transfer to milk. Milk formed in the mammary gland contains Cd, Pb, Cu, and Zn and accumulates in the alveoli, ducts and cistern. The capacity of the udder plays an important role in this. It depends on these cavities. As a result of the contraction and relaxation of muscle fibers, milk from the upper alveolar sections passes into the cistern. The nervous system plays a key role here because it controls this process.

From the upper alveolar sections, milk passes into the cistern due to the contraction or relaxation of muscle fibers. This process is controlled by the nervous system. Chronic exposure of dairy cows to heavy metals affects the process of milk production. The most dangerous ecotoxicants in this case are Pb and Cd (Portiannyk and Mamenko, 2021). Lead and cadmium disrupt the nervous system of farm animals. The accumulation of toxicants in muscle tissue and internal organs negatively affects the processes of milk formation and milk productivity, which in all cows of the control groups was lower for all types of feeding compared with the experimental groups and averaged 11.4–14.5 kg ($P < 0.001$).

Feeding the mineral-vitamin premix MP-A contributed to a lower incorporation of heavy metals, especially toxic ones such as cadmium and lead, from the gastrointestinal tract, which positively affected the general physiological condition of the animals, and at the same time the productivity, which increased on average by 1.3–1.7 times compared with the animals of the control groups ($P < 0.001$). For cows of the second experimental group with silage-hay feeding type, feeding the premix was the most effective. The milk productivity of the animals increased by 1.6 times compared with the control group ($P < 0.001$). Taking into account the environmental conditions of the experiment, this technological method in feeding cows contributed to an increase in the milk productivity of the animals in the following order. In cows with silage-root crop feeding, milk production increased by 1.3 times, with silage-hay-concentrate by 1.3 times, with silage-hay by 1.4 times and with silage-hay by 1.6 times, respectively. The main rations of dairy cows were calculated at 4500 kg per lactation, and the average daily yield was 14 kg. Milk productivity of animals less than 4500 kg is not profitable for all farms. Balancing the main ration with the developed mineral-vitamin premix contributed to a slight increase in milk production from 3477–4426 kg per lactation in the first control groups to 5444–5999 kg per lactation in the second experimental groups. A subcutaneous injection of the herbal biopreparation BP-9 from nine medicinal herbs enhanced the antitoxic effect of the premix, which also had a positive effect on the productivity of cows in the third experimental groups. Their milk productivity increased by an average of 1.3–1.7 times. Among cows in the third experimental groups, the silage-hay type of feeding proved to be the best, the milk productivity of animals increased by 1.7 times compared with the control group ($P < 0.001$).

At the end of the experiment, we managed to produce milk from animals mainly from the third experimental groups with silage-root (0.018 ± 0.002 mg/kg, cadmium; 0.014 ± 0.003, lead) and silage-hay (0.012 ± 0.002 mg/kg, cadmium; 0.014 ± 0.004 mg/kg, lead) type of feeding, which met both domestic quality and environmental safety standards, and the requirements of Regulations (EC) No. 853/2004 and No. 2023/915. In animals from the second experimental group, where the mineral-vitamin premix itself was used in the technology, the lead content decreased to 0.016 ± 0.004 mg/kg in cows with a silage-haylage diet, which also meets the domestic quality standard and the Regulation (EC). In our opinion, longer feeding of the premix contributed to a decrease in the lead content in the milk of cows of the second experimental groups and other types of feeding in this order, first with silage-hay-concentrate type diets, then in silage-hay and silage-root crops. The degree of probability compared with the data of the control group is $P < 0.01$. We tested one complex technological method of using a premix and a phytopreparation from an extract of nine medicinal herbs, which allows reducing the load on the body of productive cows with toxic heavy metals cadmium and lead, to produce environmentally safe milk.

The feeding diet plays a key role in the formation of milk in the mammary gland. A balanced diet with a special mineral and vitamin premix improves the process of milk formation, especially in animals with a larger amount of juicy feed according to the silage-root type of feeding. Intensive accumulation of milk in the mammary gland has a reflex effect on the cavities of the alveoli, ducts, and cisterns. When the walls of the udder cavities relax, their capacity increases, and the mammary gland can hold more milk. Transferring animals to triple milking under experimental conditions contributed to the improvement of the process of milk formation. In the first hours after machine milking, the intensity of milk synthesis is higher. The more time passes since the last milking, the more the process of milk formation slows down. For cows of the black-and-white dairy breed, the process of milk formation is more intense in the first six hours after the last milking. Experience of scientific research by Ukrainian and foreign scientists (Kovaleva, 2025, Gutyj et al., 2016, Savchuk et al., 2021, Portiannyk and Mamenko, 2021, Ren-ju et al., 2015) indicates the negative impact of heavy metal ecotoxicants on the internal organs liek the liver, kidneys, spleen, lymphatic and nervous systems, enzymatic and hormonal, circulatory, etc., which leads to a disruption in the production of the hormones prolactin and oxytocin, which are responsible for the process of milk formation and excretion. Toxicants block the process of oxytocin entering the mammary gland from the blood. Morphobiochemical analysis of the blood showed an increased content of pollutants. This system fails. The alveoli are squeezed weakly, the tubules contract slowly, and their cavity does not increase. There are no favorable conditions for the release of milk into the ducts of the glands. In the experiment, we selected cows with a productivity of approximately the same level of 14–15 kg per day, 4362–4636 kg per lactation. All animals were with the third lactation period.

The diets of dairy cows were balanced in terms of macro- and microelement composition, taking into account the mechanism of absorption of elements, the dynamics of movement of heavy metals – lead and cadmium – in the body of cows. We included heavy metal antagonist elements in the premixes in an amount sufficient to reduce their transfer into the blood from the digestive tract. The introduction of vitamins into the premix contributed to the restoration of homeostasis of the animal's body, improving the functioning of its organs and systems. As a result, we managed to achieve a positive effect, reducing the concentration of heavy metals in the milk of cows under different types of feeding and ensuring optimal quality, environmental safety of milk and productivity of cows ($P < 0.01$ and $P < 0.001$).

Thus, the technological method for the

production of environmentally safe milk by feeding the premix MP-A, which contains elements that are antagonists of toxic elements lead and cadmium in the second and third experimental groups of cows, limited the entry of heavy metals into the blood due to the displacement of elements from metabolic processes. A subcutaneous injection of the biological preparation BP-9 in the third experimental groups of animals under different types of feeding contributed to the improvement of the milk formation process, the secretory activity of the mammary gland, and an increase in animal productivity by an average of 1.6 times. As a result of the experiment, milk production increased to 5697–6899 kg per lactation ($P < 0.001$).

Conclusions

The production of environmentally safe milk in areas of local contamination with heavy metals of anthropogenic-technogenic, military origin requires the use of new experimentally proven technological techniques using special mineral and vitamin premixes containing heavy metal antagonist elements, biologically active essential elements selenium, iron, iodine, calcium, phosphorus, vital for animals exposed to toxic effects, vitamins, amino acid methionine, etc., which allows for maximum balance in feeding of dairy cows and restoration of homeostasis of the organism in which pollutants are incorporated. Reducing the toxic effect of heavy metals ensured the production of high-quality environmentally safe cow's milk and contributed to an increase in the average daily productivity of cows from 11–14 kg to 18–23 kg per lactation, which is one of the indicators of the effectiveness of the developed zootechnical methods. Animals fed silage-haylage and silage-haylage-concentrate diets had better lactation productivity.

Further research is aimed at monitoring the concentration of pollutants in animal feed in different soil and climatic zones of Ukraine.

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