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Biogeochemical Principles of Plant Product Quality in Agrolandscapes with Typical Chernozems

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ABSTRACT

Peculiarities of formation, distribution and fertility of typical chernozems on the territory of Europe as a whole and within the agricultural lands of Ukraine were given. It is noted that the existing agro-industrial characteristics of agricultural products least reflect the quality of raw materials and therefore are not analyzed as a factor influencing public health. The relevance of biogeochemical research of food (agricultural) raw materials and the introduction of new criteria for its quality were outlined. The purpose of the presented research was to expand the quality indicators of agricultural products on the basis of topical structure of agricultural landscapes and biogeochemical criteria for evaluating "typical chernozems – cereals and vegetables" systems. A system of biogeochemical parameters and quality criteria of plant products containing two components has been developed. The first component is the spatial differentiation of natural and agro-technological features of agrolandscapes (systems of rocks-typical chernozems-cultures), which highlight the prevalence of nutrients in bedrock, particle size distribution of typical chernozems and the ratio of their prevalence within the administrative regions of Ukraine. There are 12 groups of agricultural landscapes that differ in these features. A set of biogeochemical parameters for the distribution of essential elements in the components of the agricultural landscape, criteria for their ecological balance and impact on the quality of agricultural raw materials.Implementation of the proposed criteria for the quality of agricultural products was carried out on the territories of two agrolandscapes of typical chernozems in the Kyiv and Poltava regions.It was established that the physico-chemical balance of Zn, Cu and excess Mo in the rocks and soils of the agro-landscape of the Right Bank Forest-Steppe is not consistent with biogeochemical deficiency of copper and, in part, zinc in cereals (oats). The physico-chemical balance of Zn, Cu in the soils of the agro-landscape of the Left Bank Forest-Steppe does not agree with the biogeochemical deficiency of zinc in vegetable crops (potatoes, carrots, and beets). On the basis of the biogeochemical criteria for the distribution of Zn, Cu, Mo in agricultural landscapes, the proposed territorial measures to improve the quality of grain and vegetable products to prevent copper and zinc "hidden hunger" in the population.

Keywords: soils, biogeochemistry, productivity, product quality, agrolandscape, micronutrient balance, comprehensive assessment.

INTRODUCTION

Chernozems are distributed in the continental biogeographical region of Europe, which occupies the central part of the continent from France in the southwest to the Russian Federation in the northeast. Chernozems are the most fertile soils on Earth, which are able to provide the highest yields of crops. That is why the quality of agricultural products obtained on chernozems significantly affects the quality of food and nutrition of the population of each state as a whole [Sobchyk, 2013, Sobchyk, et al., 2010].

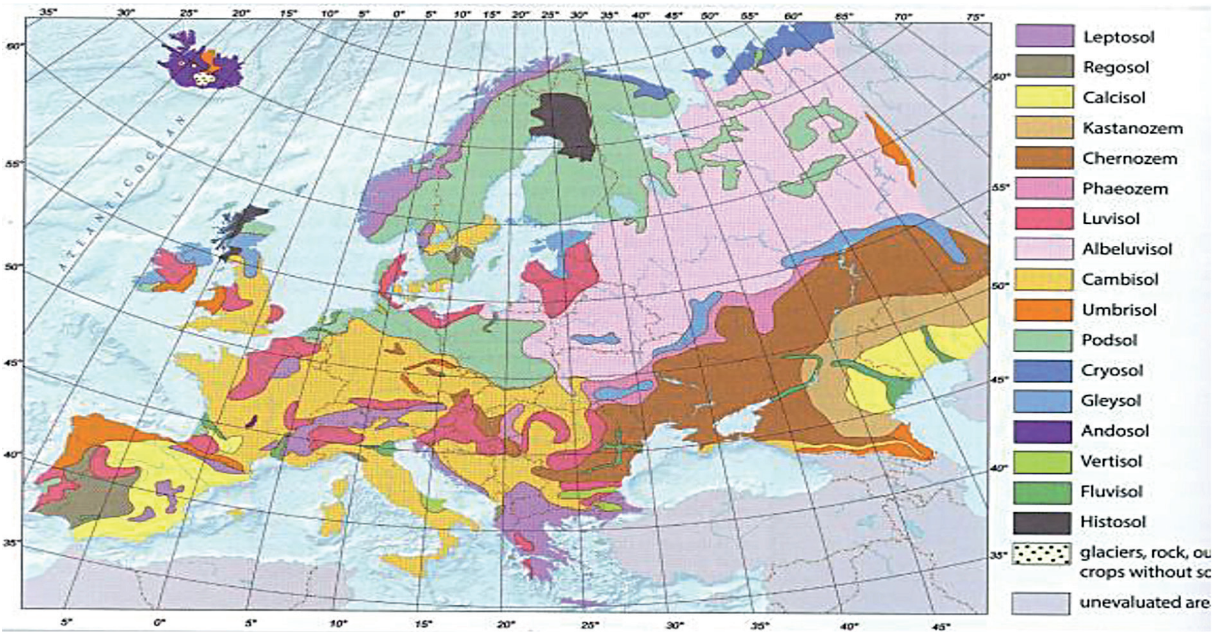

Figure 1. Distribution of chernozems in Europe territory [Chemistry, 2012]

Chernozems occupy 9% of Europe, a quarter of which, 0.25 million square km, is located within Ukraine (Fig. 1) [Chemistry, 2012]).

One third of Ukraine's chernozems belong to typical chernozems, which make up, 7.2% of European chernozems [Baluk, et al., 2010]. Typical chernozems of Ukraine are widespread in the natural-agricultural zone of the Forest-Steppe and have the highest degree of plowing – 95.3%. Thechernozems of the Forest-Steppe of Ukraine were formed on the Eastern European polygenic plain in the areas of forest plains and floodplain terraces of the Podil and Prydniprovska uplands. Underlying Quaternary rocks here are crystalline rocks of the Ukrainian Shield and sedimentary deposits of the Dnieper-Donetsk basin. The originof chernozems of the Forest-Steppe is due to their formation under meadow-steppe vegetation on Quaternary forest deposits and loess loams with good surface and internal drainage in semi-humid warm climate. Unwashed type of water regime, active biological cycle with the formation and humification of a significant part of organic matter determine the accumulative type of soil formation in relation to humus, nutrients and carbonates.

That is why the agrochemistry of typical chernozems is distinguished by two leading features. The first feature is a significant humus content and isohumus profile up to a thickness of 150 cm: the humus content in the arable layer (0–30 cm) is determined by particle size distribution and hydrothermal parameters of the warm period and ranges from 2.5–3.5% on light loam to 5.5–6.0% on heavy loams and light clays.The second is the saturation of bases and the presence of carbonates in the main horizons: calcium absolutely dominates among the absorbed cations, with a neutral water pH 6.7–7.3 and hydrolytic acidity up to 1–2 mg-eq/100 g. Their modern geochemical composition reveals the processes of low physicochemical concentration of S, B, Ca, Si, K, Ba and the scattering of virtually all other essential chemical elements that are vital for biocenoses and the human body [Klos, 2012, Yehorova, 2018, Barroso, 2022]. Such geochemical and agrochemical features of typical chernozem largely reveal the mobility of nutrients in the system "soils – crops", their biogeochemical features and the formation of the quality of agricultural products.

LITERARY REVIEW

The main economic features of typical chernozems, as well as land resources of Ukraine as a whole, are the total crop yield, soil humus and basic macronutrients, crop rotation, as well as planar soil erosion as the main indicator of their degradation [Yatsuk, et al., 2019, Dreshaj A. et al., 2022]. The defining component of the analysis of the agricultural sector of the Ukrainian economy is the volume of agricultural consumption by the population [Prokopenko O.M. et al., 2019].

Significant volumes of grain and industrial crops are grown on typical chernozems lands, the quality of which directly affects the health of at least 40% of the population of Ukraine, as well as consumers of export products in European countries.The main directions of agricultural production in Ukraine as of 2010 was the cultivation of cereals and industrial oilseeds [Rudenko L.G. et al., 2009].Between 2005 and 2018, sown areas, such as corn for grain, gradually increased up to 6 times. With a high genetic potential of productivity, modern hybrids of this crop, which is less risky to grow than winter wheat, underclimate change conditions are able to form a much higher level of grain yield, which makes the overall picture of grain production in Ukraine quite favorable, reaching 78 quintals per hectare [Petrychenko V.F. et al., 2019].

In terms of agricultural product quality, Ukraine's agricultural science is largely focused on improving the effective yield of crops and their phytosanitary status, including pests of various groups.Sometimes these indicators are added to the levels of the main nutrients and toxic substances - protein and sugar, the presence of certain pesticides and radionuclides, etc. [Balyuk S.A. et al., 2016].

Natural and anthropogenic processes of originationand degradation of typical chernozems determine both the spatial heterogeneity of their structure and the differentiation of the quality of agricultural products. The study of individual biochemical components of agricultural products indicates their certain dependence on agrochemical parameters of typical chernozems (Table 1).

Biogeochemical principles and components of the quality of plant agricultural products remain beyond the attention of domestic biologists, agroecologists and agrochemists. It should be noted that similar approaches can be observed in animal husbandry (meat weight, milk yield, number of eggs).

On the basis of the consumer basket, there are annual estimates of calories, protein, fat, and calcium and iron consumed by one Ukrainian, which are 872 mg / day and 20.2 mg / day, of which 32% and 80% [Prokopenko O.M. et al. 2019] of plant products enter the body, respectively. However, considering the figures of total crop yields and "gross consumption", it becomes virtually impossible to assess the quality of consumer products and to distinguish crops with low or dangerous quality for the population. It should be emphasized that the existing normative characteristics of Ukrainian crops are the only open quantitative assessments of these agrocenoses, but they reflect little information about the quality of agricultural products and do not consider their impact on the health of Ukrainian population. It is customary to leave most of the nutrients outside of agronomic and agrochemical research in Ukraine.

Meanwhile, international documents draw the attention of agricultural science to the problem of imbalance (lack or excess) of nutrients in food,

Table 1. Agrochemical indicators of typical chernozem and their influence on the protein content in winter wheat grain in the Forest-Steppe of Ukraine [Balyuk S.A., et al., 2016]

Physico-chemical parameters of typical chernozem	Intervals of values of the typical chernozem indicator	Protein content in winter wheat grain,% under conditions:	
		Natural fertility (without fertilizers)	Application $N_{90}P_{90}K_{90}$
Humus, %	2.0–3.0	11.0	10.8–11.2
	3.0–5.0	11.3	11.5
	more 5.0	11.9	11.9–12.4
pHsol, units	less 5.5	11.4	11.3–11.4
	5.1–5.5	11.1	11.9–12.1
	4.6–5.0	12.9	11.1–13.5
P_2O_5, mg/kg	less 51	11.4	11.4–12.1
	51–100	11.2	11.6–11.7
	100–150	12.4	11.2–11.3
	more 150	12.1	11.2–11.4
K_2O, mg/kg	less 80	10.8	11.3
	80–120	11.8	11.4–11.6
	120–180	11.8	11.3
	more 180	11.5	11.1–11.6

including "hidden hunger of the population", which is transformed into an imbalance of nutrients in humans, livestock, and poultry. The multifactorial nature of the problem of agricultural product quality requires consideration of research by specialists in specialized fields – agrochemists, botanists, phytopathologists, microbiologists and soil scientists and requires a holistic approach to the analysis of the "soil – agricultural products – man" system. Such a system of research was developer in the last century by the fundamental works of V.I. Vernadsky on biogeochemistry and practically embodied in the theory and practice of biological and ecological geochemistry by Vinogradov, V.V. Kovalsky, V.V. Yermakova and others. [Kovalsky V.V., 1978., Ivanov V.V., 1994]. In recent years, systematic research in this area has been conducted by the Institute of Agroecology and Nature Management of NAAS [Yehorova T.M., 2021., Yehorova T.M., et al., 2020, Yehorova T.M. 2018., Palapa N.V., et al., 2009, Sozinov O.O., etc. 1994].

The quality of agricultural raw materials is the basis of product quality. Only the latter has a wide range of characteristics and evaluation criteria, among which, today, the content of nutrients (protein, sugar, etc.) and contamination with pesticides as well asradionuclides has legal restrictions.At the same time, the morbidity of the population and livestock (as well as individuals) due to the imbalance of essential (nutrient) elements in the human body has long been beyond doubt among physicians and veterinarians. The pharmacological network of Ukraine alone offers hundreds of drugs that will enrich the body with J, Se, Zn, Co, Mo, Ca, Ba, P, etc. At the same time, neither the buyer nor the seller has the slightest idea of the need, benefit or danger of "such enrichment" and the need for a preliminary examination for the content in their body of the relevant essential elements.Despite the importance for the food industry and pharmacological adjustment of public health, biogeochemical assessments and their importance as indicators of the quality of agricultural raw materials, there is still no place in the system of agrochemical certification of agricultural land.

The "system" is working and it is not possible to stop it in the near future. However,it is possible to introduce biogeochemical quality standards into the evaluation system of each batch of food raw materials.That is why it is advisable to introduce such criteria in the scientific and practical development of our agricultural science. Such criteria will be an impetus for the food industry, which is able to increase or decrease (block) in the products of certain chemical elements, which will improve public health by enhancingthe quality of products in terms of nutrients.

According to the laws of the biosphere, set out by V.I. Vernadsky, and accordingly the agrosphere, the connection of soil with vegetation is due to biological cycles of substances and biogeochemical cycles of chemical elements [Yehorova T.M., 2021]. These cycles contain leading tools for assessing the relationship of crops to soil and are determined by biogeochemical methods, characteristics and criteria. Therefore, it is the biogeochemical criteria for the quality of crops that are a complex multifactorial feature of the impact of soil on the crop, as well as the level of humus in the soil and its supply of nutrients and chemical elements.

During the second half of the last century, biogeochemical ideas were embodied in the formation of theory and methodology of various interdisciplinary research areas – landscape and ecological geochemistry, geoecology, radioecology, geochemical ecology, medical geology, microelementology, etc. For more than half a century, starting with the research of P.A. Vlasyuk and V.V. Kovalsky (60–70s of the 20th century), the biogeochemistry of Ukraine has been making its way in the environment of agricultural sciences and land use systems. In fact, the results of biogeochemical processes are the provision of food raw materials with balanced levels of nutrients, their excess or deficiency in accordance with the concepts obtained in biogeochemical generalizations of geochemical ecology conducted in the 1960-90s in territories of endemic or background provinces of Ukraine and other countries, and also modern regional research in the field of animal husbandry of our state.

At the same time, the embodiment of VI Vernadsky's biogeochemical ideas in the study of the agrosphere requires extensive practical research to obtain informative results.

The purpose of the presented researchwas to expand the quality of agricultural products by forecast characteristics (based on the topical structure of agricultural landscapes) and biogeochemical criteria for evaluating systems "typical chernozems – cereals and vegetables".

The object of the presented study is forecasting the supply of agricultural crops with micronutrients in agrolandscapes of typical chernozems. Subject of study – biogeochemical criteria for the formation of the quality of agricultural raw materials by the content of essential trace elements of different levels of biophilicity. Research methods – historical, biogeochemical, agrochemical, ecological-geochemical, agronomic. Laboratory measurements were performed in stationary physical and chemical laboratories of the Institute of Agroecology and Nature Management of NAAS, NSC "Institute of Agriculture" NAAS and SE "Ukrainian Geological Company".

The developed system of biogeochemical parameters and quality criteriaof plant products contains two components. The first component constitutesspatial differentiation (agrolandscapes) of "rocks-typical chernozems-cultures" systems taking into account the prevalence of nutrients in underlying rocks, physico-chemical (particle size distribution) of typical chernozems and the ratio of their distribution and gross (statistically published) crop yields within territory of Ukraine. This provides a basis for qualitative forecasting of plant nutrients, crop selection, intensity of anthropogenic transformations of the soil-plant system and the importance of the quality of crops of certain agricultural landscapes in the overall balance of product evaluations of the relevant administrative region. The second component is theecological assessment of biogeochemical nutrient chains using geochemical, biogeochemical and medicoecological criteria. This provides a basis for quantifying the supply of plant products with nutrients (in certain crop rotations, agrochemical and varietal characteristics of crops) and its possible impact on the morbidity of the population and domestic animals.The application of biogeochemical criteria to assess the quality of crops and raw materials opens up new opportunities for improving the health of both the population of Ukraine and livestock. Formally, it is able to provide new mechanisms for the transition to biocentric (ecological) crop production from anthropocentric, prevailing in our country to this day.

The authors'previous scientific and methodological developments have outlined the concept of agrolandscape, biogeochemical chain and its links. Each soil-plant system is considered as one that is in a state of dynamic equilibrium, like any other natural formation, and develops in the direction of its natural physico-chemical and biological organization [Yehorova T.M., et al., 2020]. Within the framework of agroecological research of Ukraine, the concept of biogeochemical chainhas been specified. This is a system of conjugated within the agro-landscape links "rocks – soils – waters – living matter of natural and agricultural plants", which are interconnected by processes of biogenic and physico-chemical natural-manmade migration of biophilic (nutrient) chemical elements. Such limitations are explained by the fact that modern agricultural research lacks both agro-landscape systematization of agricultural lands and combined information on the chemical composition of rocks, soils, water plants, animal and population diets.

Agro-landscape systematization of agricultural lands, as well as agro-landscape in general, is usually identified with such parameters as soil type, its acidity and humus content in the arable layer 0–30 cm. Such information is important, but does not reveal the features of chemistry and biogeochemical processes both in the agro-landscape and in the soil as a separate component. To solve agroecological problems, spatial systematization and mapping of lands should also include the characteristics of chemistry (geochemistry) of bedrock and natural waters, natural biomass and plant productivity, which largely shape the ecological and biogeochemical features of lands.

RESULTS AND DISCUSSION

The biogeochemical system of plant quality criteria introduces two components into agroecological research. The first is the spatial differentiation (agrolandscapes) of "rocks-typical chernozems-cultures" systems, taking into account the prevalence of nutrients in underlying rocks, physico-chemical (particle size distribution) of typical chernozems and the ratio of their distribution and gross (statistically published) yield at administrative regions of Ukraine. The second is identification and ecological assessment of biogeochemical nutrient chains based on biogeochemical criteria.

Spatial differentiationof systems "rocks - typical chernozems – plant" highlights the peculiarities of the formation and functioning of biogeochemical chains of biophilic elements.

While studying the distribution of typical chernozems on the territory of Ukraine, regional groups of agrolandscapes have been identified, the biogeochemical features of which directly form a certain differentiation of the quality of the final agricultural products. *Three natural and agro-technological features* of differentiation of agrolandscapes that have an impact on the biogeochemical characteristics of nutrient chains have been selected. The first is geochemical and metallogenic specialization in biophilic elements and bedrock crystalline rocks of the Ukrainian Shield and sedimentary deposits of the Dnieper-Donetsk basin (as an indicator of the main source of chemical composition of soil-forming rocks and soils); the second is the granulometric composition of typical chernozems (as an indicator of stable physicochemical absorption capacity of the soil profile –in contrast to the humus content, which varies widely in profile and depends on agronomic measures); the third involves groups of crops by different categories of nutrient requirements (as an indicator of the needs of the main nutrients and microfertilizers).

According to the first natural-agro-technological feature, in the predominant area of distribution of typical chernozems underlying rocks are enriched, among the biophilic elements, only with iron; much smaller areas are characterized by concentrations of zinc and copper; local metallogenic and geochemical zones specialized in phosphorus, potassium, calcium, sulfur, molybdenum, manganese, and lead [Galetsky L.S. et al., 2001, Yehorova T.M. 2020, Yehorova T.M., et al., 2007].

1. Agrolandscapes of rare-earth specialization of crystalline rocks of the province of the Ukrainian Shield on mineralization of tariffs by concentrations of biophiles in the Khmelnytsky metallogenic zone Mo, Cu.
2. Agrolandscapes of lithophilic and chalcophilic specialization of crystalline rocks of the Ukrainian Shield province in the Bila Tserkva structural-metallogenic zone on Zn, Cu, Mo, P, K, Ca, and Fe.
3. Agrolandscapes of titanium-phosphorus vanadium and chalcophilic specialization of crystalline rocks of the Ukrainian Shield province in the Bila Tserkva structural-metallogenic zone on P, Mn, Zn, Cu, Mo, and Fe.
4. Agrolandscapes of complex lithophilic or unmanifested specialization of crystalline rocks of the Ukrainian Shield province in the Bila Tserkva structural-metallogenic zone without biophiles.
5. Agrolandscapes of chalcophilic specialization of sedimentary sediments of the Dniester-Black Sea province in the Dubno-Gorodok metallogenic zone on Zn, Cu, Pb.
6. Agrolandscapes of chalcophilic specialization of sedimentary sediments of the Dnieper-Donetsk province in the Central structural-metallogenic zone on Zn, Pb, S.

According to certain groups of agrolandscapes, there are opportunities to clarify the choice of crops according to their needs in nutrients, precisely because the natural state of the agrolandscape is characterized by enrichment in certain elements. For example, agrolandscapes of the first group are distinguished by the enrichment of rocks and (most likely) soils Mo, Cu. Buckwheat and alfalfa, and, to a certain extent, oats, rice, cabbage, onions, are in high demand for both of these microelements [Prokopenko O.M. et al., 2019].

According to the second natural and agro-technological feature, the predominant areas of typical chernozems by granulometric composition are classified as medium loam and, to a lesser extent, light loam [Krupskyi M.K. et al., 1972, Maps].

1. Agrolandscapes with chernozems are typical dusty-medium loam.
2. Agrolandscapes with typical chernozems are coarse-grained-medium-loamy.
3. Agrolandscapes with chernozems are typical coarse-grained light-loam.

According to certain groups of agrolandscapes, the absorption complex of typical chernozems functions, more precisely, its mechanical sorption capacity. For example, in the agricultural landscapes of the third group, the removal of nutrients from the soil (physico-chemical agro-technogenic scattering and anthropogenic transformation) will be most intense with the combined enrichment of plant products.

According to the third natural and agro-technological feature, the predominant areas of typical chernozems are used for growing cereals and industrial oilseeds. Such information is publicly available only from statistical collections, in which information is grouped by administrative region [Prokopenko O.M. et al., 2019]. Without touching on the “unnatural” content of such statistics, as well as the limited list of “food nutrients” iron and calcium, the authorsmust rely on this information. Summarizing the digital material on the area of distribution of typical chernozems, areas under crops and crop yields (cereals and legumes, winter wheat and sunflower) by administrative regions of Ukraine, the following three groups of agricultural landscapes were identified.

1. Agrolandscapes of typical chernozems, with prevalence in large (60-90%) areas of administrative regions, which correlates with increased yields of cereals and legumes (66-70 kg/ha), wheat (43–55 kg/ha) and sunflower 29-31 c/ha)–Kyiv, Poltava, Sumy, Khmelnytsky regions.
2. Agrolandscapes of typical chernozems, with a distribution on insignificant (20–30%) areas of administrative regions, which correlates with reduced yields of cereals and legumes (45 c/ha), wheat (36 c/ha) and sunflower (25 c/ha) – Kirovograd region.
3. Agrolandscapes of typical chernozems, with prevalence in different (20–70%) areas of administrative regions and variable yields of cereals and legumes (38–71 kg/ha), wheat (34–38 kg/ha) and sunflower (28–32 c/ha) – Kharkiv and Cherkasy regions.

According to certain groups, it is advisable to distinguish between the yield levels on different soils. This makes it possible to reduce “food requirements and pressure” and areas with gray podzolic soils and obtainreal causal links between areas and the results of growing plant products of a certain quality, as well as to form regionally spatially differentiated measures to improve agricultural quality.

Ecological assessment of biogeochemical nutrient chains using geochemical, biogeochemical and medico-ecological criteria is based on the developed spatial differentiation of agrolandscapes of typical chernozems.

The second component of the system of biogeochemical evaluation of agricultural products includes the combined evaluation of different links of the food biogeochemical chain (rocks, soils, crops) in the direction and results of the cycle of elements.

The development of such criteria is based on the postulates of the teachings of VI Vernadsky on the unity of all parts of the biosphere and biogeochemical cycles and chains as semi-closed systems that combine rocks, waters, soils, phytocenoses and zoocenoses [Yehorova T.M., 2021].

The set of biogeochemical parameters of the distribution of essential elements in the components of the agro-landscape includes the coefficients that allow determiningthe distribution and sequence of processes of transition (migration) of elements in the components of the agrolandscape. Such coefficients are widely described by us [Yehorova T.M. et al., 2020, Palapa N.V., 2009] and highlight the features of two types of natural and man-made geochemical migration. Coefficients of biogenic migrationare the main estimates of the nature and intensity of the transition of nutrients in the upper links of the biogeochemical chain - soil and plant. Informative biogeochemical significance is the coefficient of biological absorption of elements by the plant from the soil (Ax) and the transition coefficient (CT*x*), the coefficient of balance of essential elements in soils (CBG) and dry matter of plants (CBD). Coefficients of physicochemical migration are estimates of the nature and intensity of the transition of nutrients in the lower and middle links of the biogeochemical chain – water, bedding and soil-forming rocks. Informative biogeochemical significance are Clark Concentration (CCI) and Ecological Concentration Coefficient (ECI). Ecological concentration factor is used for the purpose of traditional detection of man-made contamination of soils and agricultural products. It should be emphasized that agricultural science does not separate the pollution of arable land with heavy metals and radionuclides from the concept of “maximum allowable concentrations” of chemical elements in soils and crop products. Land grading includes comparisons with the maximum allowable concentration as the only reliable approach to assessing the quality of soils and, a priori, and agricultural products grown on it. At the same time, other Earth sciences are quite critical of the application of maximum allowable concentration in the theory and methodology of geoecology, biogeochemistry, landscape geochemistry, geochemical ecology, ecological geochemistry. Despite the fixed maximum allowable concentration conditions for all, these sciences use for analysis the background levels of chemical elements, which are the basis for calculating the coefficients of concentration and total soil contamination by heavy metals.

To calculate these coefficients, the ratio of nutrients in the soil-plant system (in the calculations of Ax, CTx), threshold levels of elements in soils and vegetation (in the calculations of CBG and CBR), maximum allowable concentrations (in the calculations of ECI), clarke rocks and plant ash (in the calculations of CCI) are used. These quantitative estimates of the content of chemical elements in rocks, soils, vegetation and continental waters are contained in various reference books on ecology, biogeochemistry and agrochemical

Table 2. Biogeochemical criteria for assessing the quality of agricultural products on the content of Zn, Cu, and Mo

Nutrient	Normality criteria and balance of biogeochemical chains						Criteria for violation of the norm and imbalance of biogeochemical chains					
	Ax	CTx	CBG	CBR	ECI	CCI	Ax	CTx	CBG	CBR	ECI	CCI
1	2	3	4	5	6	7	8	9	10	11	12	13
Zn	10–12	42–66	1–2.3; 1–5*	1–25	≤ 1	0.5–1.5	< 10	<40	< 1; > 2.3 and 5*	< 1; > 25	> 1	< 0.5; > 1.5
Cu	2–5	no data	1–10; 1–2**	1–13	≤ 1	0.5–1.5	< 2	no data	< 1; > 10 and 2**	< 1; > 13	> 1	< 0.5; > 1.5
Mo	9–19	no data	1–2.6; 1–50*	1–15	≤ 1	0.5–1.5	< 9	no data	< 1; > 2.6 and 50*	< 1; > 15	> 1	< 0.5; > 1.5

Note: * movable form for oxalate buffer, *pH* 4.8; ** soluble form for 1N KCl, *pH* 3.3.

monitoring of soils [Yehorova T.M. 2018., Yatsuk I.P. et al., 2019., Kovalsky V.V., 1978., Yehorova T.M., 2021., Yehorova T.M., et al., 2020.]. For example, for Kein calculations, the maximum concentration limits of Zn, Cu and Mo soils in the form of gross –55,33 and 2 mg/kg, mobile soils –23.3 and 0.3 mg/kg, oat grain dry matter – 50,10 and 0.6 mg/kg, dry matter of vegetables –10.5 and 0.2 mg/kg [Yehorova T.M. 2018., Yatsuk I.P. et al., 2019., Yehorova T.M., 2021.].

However, the calculations of ratios and coefficients, mostly for a particular component of the agro-landscape (as a rule, soil), do not highlight the features of the agro-landscape system as a whole, including the quality of agricultural raw materials produced within it.Such an assessment requires a comprehensive biogeochemical assessment of the system. To this end, biogeochemical quality criteria for assessing the quality of agricultural products as a result of redistribution of nutrients in the "rocks – soils – crops" system (Table 2) have been developed and implemented on the example of Zn, Cu, and Mo.

Biogeochemical criteria for the quality of agricultural products are based on the assessment of biogeochemical chains available for analysis of essential, or biophilic and nutrient, elements in the "rocks – soils – crops" system. Such systems have a spatial differentiation, which were systematize by individual agricultural landscapes or their taxonomic groups. Studies of biogeochemical chains include the parameters and criteria that highlight the levels of balance of elements and their generalization for the territory of a particular agro-landscape. Such generalization should become an element of the certificate of food raw materials and a tool for choosing measures for its processing, for example, as was the washing of industrial crops (potatoes, beets), which are collected in radioactive areas.

The introduction of biogeochemical criteria for the quality of agricultural products was performed in the territories of two research sites, biogeochemistry and agroecology of which were studied during 2008–2018 (Table 3).

On the territory of the Right-Bank Forest-Steppe of Ukraine,the agrolandscape of typical chernozems coarse-grained light loam with lithophilic and chalcophilic specialization of crystalline rocks of the Ukrainian Shield province in Bila Tserkva structural-metallogenic zone (Zn, Cu, Mo, P, K, Ca, Fe) with their significant spread in the Kiev region were studied. The research area belongs to the territory of the Research Enterprise "Experimental Farm" Skvyrske", which is administratively part of the Skvyra district of Kyiv region in the interfluve of the left tributaries of the river Ros. Landscape and geographical features of this area determine the distribution of denudation flat-undulating with residual humps of loess height on sedimentary deposits, where chernozems typical are interspersed with gray podzolic soils; the valleys of the rivers on the right bank of the Ros River (Domantovka and Berezanka rivers) include narrow floodplains and terraces, within which there are outcrops of crystalline rocks of the Ukrainian Shield.

Peculiarities of the structure of the studied agrolandscape indicate the presence of excessive concentrations in the bedrock of a number of essential biophilic elements and the possibility of

Table 3. Characteristics of components of agrolandscapes of typical chernozems of the Forest-Steppe of Ukraine (range of values)

<table>
<tr><th rowspan="2">Characteristics of agrolandscapes</th><th rowspan="2" colspan="2">Regional estimates of the Forest-Steppe of Ukraine**</th><th colspan="3">Estimates of arable land of autonomous agrolandscapes of typical chernozems of the Forest-Steppe of Ukraine</th></tr>
<tr><th>Left-bank Forest-Steppe (Poltava region, Berezotocha village, 2008-2009) [16]</th><th colspan="2">Right-bank Forest-Steppe (Kyiv region, Public enterprice “Research farm Skvyrske”, 2016-2018), Egorova TM, Sapsay TP</th></tr>
<tr><td>1</td><td colspan="2">2</td><td>3</td><td colspan="2">4</td></tr>
<tr><td colspan="6">Underlying rocks</td></tr>
<tr><td>Zn, mg/kg</td><td colspan="2">no data</td><td>63</td><td colspan="2">34</td></tr>
<tr><td>Cu, mg/kg</td><td colspan="2">no data</td><td>27</td><td colspan="2">22</td></tr>
<tr><td>Mo, mg/kg</td><td colspan="2">no data</td><td>1.0</td><td colspan="2">1.1</td></tr>
<tr><td colspan="6">Soil-forming forests and loess loams (gross and mobile forms)</td></tr>
<tr><td>Zn, mg/kg</td><td colspan="2">56–64</td><td>56.0**</td><td>25–62;
44***</td><td>0.1–0.4*
0.3</td></tr>
<tr><td>Cu, mg/kg</td><td colspan="2">14.2–19.0</td><td>14.3**</td><td colspan="2">6–29
18</td></tr>
<tr><td>Mo, mg/kg</td><td colspan="2">2.9-3.4</td><td>3.0**</td><td colspan="2">0.5–13.0
6.8</td></tr>
<tr><td colspan="6">Chernozems typical</td></tr>
<tr><td>Humus, %</td><td colspan="2">2.5–6.0</td><td>1.1–4.0</td><td colspan="2">1.4–6.0</td></tr>
<tr><td>The sum of absorbed bases, mg-eq / 100 g</td><td colspan="2">to 45</td><td>no data</td><td colspan="2">18.3–26.9</td></tr>
<tr><td>pH water</td><td colspan="2">6.7–7.3</td><td>no data</td><td colspan="2">no data</td></tr>
<tr><td>pH salt</td><td colspan="2"></td><td>5.8–7.4</td><td colspan="2">5.5–7.7</td></tr>
<tr><td>Hydrolytic acidity, mg-eq / 100 g</td><td colspan="2">1–2</td><td></td><td colspan="2"></td></tr>
<tr><td>N easily hydrolyzed, mg/kg</td><td colspan="2">no data</td><td>49,0-168,0</td><td colspan="2">no data</td></tr>
<tr><td>P_2O_5, mg/kg</td><td colspan="2">105</td><td>154–3429</td><td colspan="2">197–17406</td></tr>
<tr><td>K_2O, mg/kg</td><td colspan="2">101</td><td>132–2081</td><td colspan="2">3374–46518</td></tr>
<tr><td>Zn, mg/kg</td><td colspan="2">33–65</td><td>0.6–38.8*
19.9</td><td>32–67;
50</td><td>0.2–1.7*
1.0</td></tr>
<tr><td>Cu, mg/kg</td><td>10–21;</td><td>0.06–0.07*</td><td>0.1–0.6*
0.3</td><td colspan="2">9–33
21</td></tr>
<tr><td>Mo, mg/kg</td><td colspan="2">1.0–1.7</td><td>no data</td><td colspan="2">0.5–14.0
7.3</td></tr>
<tr><td colspan="6">Cereals and vegetables (dry matter)</td></tr>
<tr><td>Zn, mg/kg</td><td colspan="2">no data</td><td>2.5–4.4
3.5</td><td colspan="2">18.9–26.2
22.6</td></tr>
<tr><td>Cu, mg/kg</td><td colspan="2">no data</td><td>0.5–2.6
1.1</td><td colspan="2">1.0–2.0
1.5</td></tr>
<tr><td>Mo, mg/kg</td><td colspan="2">no data</td><td>no data</td><td colspan="2">2.0–4.0
3.0</td></tr>
</table>

Note: * moving forms; ** regional estimates based on literature data [Balyuk S.A., et al., 2010, Klos V.R., et al., 2012, Prokopenko O.M. et al., 2019., Galetsky L.S. et al., 2001., Storchak N.P. et al., 1984., Zarytsky A.I. et al., 1989.]; *** in the denominator – the estimate of the average value of the median sample; no data – no data or not studied.

their excess in soils and crops. The granulometric composition of typical chernozems (coarse-grained light loam) determines the relatively high intensity of the process of agrotechnogenic nutrient dispersion for typical chernozems and, accordingly, the lowest level of fertilizer assimilation in the conditions of root nutrition and prospects of foliar feeding. Significant distribution of these agricultural landscapes in the Kyiv region forms a significant impact on the overall level of assessments of product quality and health of the population of the region.

Within the agro-landscape, the biogeochemical chains of Zn, Cu, and Mo and the quality of oats in the system "bedding crystalline rocks of the Ukrainian Shield – soil-forming rocks of loess and loess loams – typical chernozem soils – oats" were studied. Agrogenic factors in the formation of the quality of grain crops are the features of the Desnyansky variety of oats, grown in grain crop rotation, using traditional agricultural technologies and $N_{16}P_{16}K_{16}$ application. The set of biogeochemical parameters of Zn, Cu, and Mo and their impact on the quality of agricultural products in this area are summarized in Table 4.

The presented criteria for evaluating the biogeochemical chains of three essential trace elements showed that the biogeochemical features of the agro-landscape are characterized mainly by a balance of Zn, Cu and excess Mo. However, when growing oats of the Desnyansky variety using traditional technologies, a biogeochemical deficiency of copper and, partially, zinc is formed. Constant consumption of copper-deficient products can cause "hidden copper hunger" and diseases such as weakness, anemia, leukemia, bone disease, etc. To improve the quality of oat grain, it is necessary to provide additional foliar feeding of this crop with appropriate microfertilizers, mainly copper. Similar patterns of biogeochemical copper deficiency should be expected in the cultivation of other cereals, biochemical characteristics of which require it in significant quantities, namely wheat, barley, millet, corn, etc. It is advisable to focus here on the cultivation of cereals with high Mo needs – buckwheat and soybeans.

On the territory of the Left Bank Forest-Steppe of Ukraine, the agrolandscape of typical dusty-medium-loam chernozems with chalcophilic specialization of sedimentary deposits of Dnipro-Donetsk province in the Central structural-metallogenic zone (Zn, S, Pb) with their significant distribution in Poltava region was studied. The study area belongs to the residential area of the village. Berezotocha, which is administratively part of the Lubny district of Poltava region on the left bank of the Sula River.Landscape and geographical features of this area [Marynych O.M., et al., 2007] determines the distribution of loess lowlands with strong anthropogenic cover on Paleogene sediments and undulating hills, dissected by river and passable ancient valleys, gullies and ravines, places with landslides, swamps and saline chernozems.

Peculiarities of the structure of the studied agrolandscape indicate the presence of excessive concentrations in the bedrock of Zn, S - essential biophilic elements with their possible excess

Table 4. Biogeochemical parameters of Zn, Cu, and Mo in the agro-landscape of typical chernozems of the Forest-Steppe of the Right Bank and assessment of their impact on the quality of food raw materials

Biogeochemical parameters	Essential trace elements			Estimates of the impact of parameters on the quality of agricultural products		
	Zn	Cu	Mo	Content balance	Excess content	Lack of content
1	2	3	4	5	6	7
Underlying rocks of the Ukrainian Shield						
Clark Concentration (CCl)	0.7	1.0	0.8	Zn, Cu, Mo	no	no
Soil-forming rocks of loess and loess loams						
Clark Concentration (CCl)	0.3	0.5	4.5	Cu	Mo	Zn
Soils typical chernozems						
Clark concentration (CCl)	0.6	0.7	6.1	Zn, Cu	Mo	no
Ecological concentration factor (Kei)	0.04*–0.9	0.4	3.7	Zn, Cu	Mo	no
Ecological concentration factor (Kei)	1.7–3.3*	3.5	4.9	Zn, Cu	Mo	no
Oats of the Desnyansky variety						
Clark concentration (CCl)	1.1	0.8	5.0	Zn, Cu	Mo	no
Ecological concentration factor (Kei)	0.5	0.2	5.0	Zn, Cu	Mo	no
Plant balance ratio (PBR)	1.1	0.5	15.0	Zn, Mo	no	Cu
Transition coefficient (CTx)	27	no data	no data	no data	no data	Zn
Biological absorption coefficient (Ax)	7.1	1.4	12.0	Mo	no	Zn, Cu

Note: * movable form for oxalate buffer, *pH* 4.8. Calculations are given for the median values of the samples of Table 3.

in soils and crops. Particular attention needs to be paid to the possible excess of sulfur – "agronomic basis of life". It is advisable to grow oilseeds and legumes, which have high needs for sulfur (soybeans, sunflowers, mustard, canola, beans, lentils, alfalfa, peas), among which priority should be given to soybeans and sunflowers, also with high Zn needs. The granulometric composition of soils (dusty-medium-loamy) determines the average for typical chernozems intensity of the process of agrotechnogenic dispersion of nutrients and, accordingly, the average level of fertilizer absorption and prospects of different plant nutrition systems. Significant distribution of these agricultural landscapes in the Poltava region forms a significant impact on the overall level of assessments of product quality and health of the population.

Within the agro-landscape, the biogeochemical chains of Zn, Cu and the quality of vegetable crops in the system "bedding sedimentary rocks of the Dnieper-Donetsk province – soil-forming rocks of forests and loess loams – typical chernozem soils – vegetable crops" were studied.Agrogenic factors in the formation of crop quality are the different varieties of potatoes, beets, carrots and cucumbers grown in vegetable crop rotation using traditional agricultural technologies and the introduction of mostly organic fertilizers. The set of biogeochemical parameters of Zn, Cu and their impact on the quality of agricultural products in this area are summarized in Table 5.

The presented criteria for evaluating the biogeochemical chains of two essential trace elements showed that the features of this agro-landscape are characterized mainly by a balanced content of Zn and Cu.However, biogeochemical zinc deficiency is formed during the cultivation of vegetable crops. Constant consumption of zinc-deficient products can cause "hidden zinc starvation" and cause diseases such as bone deformities, growth retardation and dwarfism, myopia, impaired cellular immunity, neurosensory disorders, etc.To improve the quality of vegetable products, it is necessary to provide additional nutrition of soils and crops with appropriate microfertilizers, mainly zinc. Such patterns of biogeochemical zinc deficiency confirm the significant needs of most vegetable crops, biochemical features of which require it in significant quantities, which should be expected when growing cabbage, onions, etc.It is advisable to focus here on the cultivation of crops with high and medium Cu needs, i.e. radish, cabbage, cucumbers, cereals, etc.

Table 5. Biogeochemical parameters of Znand Cu in the agro-landscape of typical chernozems of the Forest-Steppe of the Left Bank and assessment of their impact on the quality of food raw materials

Biogeochemical parameters	Essential trace elements		Estimates of the impact of parameters on the quality of agricultural products		
	Zn	Cu	Content balance	Excess content	Lack of content
1	2	3	4	5	6
Underlying rocks of the Dnieper-Donetsk province					
Clark concentration (CCI)	0.7	0.5	Zn, Cu	no	no
Soil-forming rocks of loess and loess loams					
Clark concentration (CCI)	0.6	0.3	Zn	no	Cu
Soils typical chernozems					
Clark concentration (CCI)	0.7	0.8	Zn, Cu	no	no
Ecological concentration factor (Kei)	0.8*	0.1**	Zn, Cu	no	no
Plant balance ratio (PBR)	66*	0.1**	no	Zn	Cu
Vegetable crops (table beets, carrots, potatoes, cucumbers)					
Clark concentration (CCI)	0.2	0.6	Cu	no	Zn
Ecological concentration factor (Kei)	0.4	0.2	Zn, Cu	no	no
Plant balance ratio (PBR)	0.2	0.4	no	no	Zn, Cu
Transition coefficient (CTx)	0.2	5.1	no	Cu	Zn
Biological absorption coefficient (Ax)	7.6	9.3	no	Cu	Zn

Note: * movable form for oxalate buffer, *pH* 4.8; ** soluble form for 1N KCl, pH 3.3. Calculations are given for the median values of the samples in Table 3.

CONCLUSIONS

Significant volumes of grain and industrial crops are grown on agricultural lands of European countries with typical chernozems, the yield of which in Ukraine reaches 63 c/ha. The quality of these crop products directly affects the health of at least 40% of the population, as well as expert consumers.

The ecological features of balance of micronutrients in plant agricultural products were studied in two agrolandscapes of the Forest-Steppe of Ukraine according to biogeochemical criteria. In the agro-landscape of the Right-Bank Forest-Steppe (Kyiv region), with a balanced content of Zn, Cu and an excess of Mo in the soil, oat culture reduced the biological uptake from the soil of Zn and Cu; this can lead to their biogeochemical deficiency in grain products and contribute to the "hidden hunger" of consumers with the development of endemics of anemia, leukemia, dwarfism, etc. In the agro-landscape of the Left-Bank Forest-Steppe (Poltava region), with an excess of Zn and a lack of Cu in soils, vegetable crops are characterized by differentiation of biological absorption of Zn and Cu; this can lead to reverse biogeochemical imbalance and contribute to the "hidden hunger" of Zn in consumers with the development of endemics of dwarfism, myopia, bone diseases, etc. Taking into account biogeochemical criteria, in the studied agrolandscapes it is advisable to focus on growing the crops with high Mo needs (buckwheat, soybeans) as well as high and medium Cu needs (radish, cabbage, cucumbers, and cereals), respectively, in the Right Bank and Left Bank Forest-Steppe.

Biogeochemical criteria indicate the absence of a direct dependence of the quality of agricultural products on the composition of the soil for the content of nutrients in agricultural landscapes with typical chernozems. This is an informative basis for forecasting the quality of agricultural products and further development of effective measures to enhanceit as a factor in improving consumer health.Their generalization on an agrolandscape basis should become an element of the certificate of food raw materials and a tool for choosing measures for its processing.

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