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Ways of optimization of lead-polluted black earth soils in the soil-plant system

***Yana O. Biletska*[1],**
DSc (Engineering), Professor, Department of International E-Commerce and Hotel and Restaurant Business,
[1]V. N. Karazin Kharkiv National University, 6 Svobody Sq., Kharkiv, 61022, Ukraine,
e-mail: monika3384@ukr.net, https://orcid.org/0000-0001-8060-6579;
***Alla N. Nekos*[1],**
DSc (Geography), Professor, Department of Ecological Safety and Ecological Education,
Educational and Scientific Institute of Ecology
e-mail: alnekos999@gmail.com, https://orcid.org/0000-0003-1852-0234;
***Anastasia O. Bekhter*[2],**
Postgraduate Senior Secretary, Secretary of the Department of Ecological Biotechnology,
[2]Lodzinsiy University of Technology, 3B, 605 Polytechnic St., Lodz, 90-535, Poland,
e-mail: bekhteranastasiia@gmail.com, https://orcid.org/0000-0001-6024-5278;
***Anna S. Krivtsova*[1],**
PhD (Economics), Associate Professor,
Department of International E-Commerce and Hotel and Restaurant Business,
e-mail: anna.perepelytsia@karazin.ua, http://orcid.org/0000-0002-2306-7975;
***Olga I. Brayninger*[3],**
PhD Student, [3]State Biotechnological University,
44 Alchevskych St., Kharkiv, 61000, Ukraine,
e-mail: olya.braininger@gmail.com, https://orcid.org/0000-0001-7730-713X

ABSTRACT

Formulation of the problem. Ecological safety of soils and cultivation of ecologically safe food products of plant origin is one of the most urgent problems of today. Ensuring the environmental safety of food raw materials and food products is one of the main tasks that determine the health of the human population and the preservation of its gene pool.

Analysis of recent research and publications. Toxic effects of Pb on human bodies have been confirmed by numerous clinical studies that have shown the negative effects of heavy metals on the nervous, cardiovascular, immune systems and oncology. The works is devoted to the development of detoxification techniques, in which scientists proposed to reduce the content of heavy metals in chernozems by detoxifying soils by growing battery plants on them, which will «extract» heavy metals from soils disinfecting them. The disadvantage of the proposed technologies is the economic costs borne by farmers, producers and consumers. Farmers will suffer financial losses due to idle sown areas and the cost of seed. Producers will be forced to raise prices for the final food product as a result of reduced consumer purchasing power.

Formulation of the purpose of the article. The aim of the article is to determine ways to optimize lead-contaminated chernozem soils in the system «soil – plant» (on the example of chernozem soils within the test sites on the territory of the collection nursery «Agrotek» in Kyiv region).

Presentation of the main research material. The article presents the results of a study of ways to optimize lead-contaminated chernozem soils in the system «soil – plant». The objects of the study were soybean and chickpea varieties of different vegetation varieties, namely: ultra-early varieties, maturation period 95… 105 days. Medium, maturation period 100…115 days. Medium-ripe varieties maturation period115…125 days. Early ripening varieties of chickpeas growing period 95…115 days, and medium-ripe sotu chickpeas, growing period 115…125 days. Experimental studies were conducted during 2019 – 2021 within the test sites on the territory of the collection nursery «Agrotek» in Kyiv region. The method of ion exchange and liquid chromatography on the liquid chromatograph Shimadzu LC-20 (Japan). Studied the variability of nutrients (protein, fat, carbohydrates) in soybeans and chickpeas of different vegetation varieties. With the help of the MATLAB program, mathematical optimization was carried out and the five-year dynamics of protein, fat, and carbohydrate content in legumes grown on chernozem soils of the «Agrotek» collection nursery in the Kyiv region was determined. By the method of inversion-voltammetry with the help of voltammetric analyzer «ABA-3» (Russia) which is equipped with an indicator electrode for the determination of lead, the concentration of Pb in chernozems and soybeans and chickpeas with different protein content was studied. Concentrations of Pb in soybean and chickpea grains depending on the chemical composition of soils for cultivation were grown and studied at the test sites of the «Agrotek» collection nursery.

Conclusions. As a result of experimental studies, it was found that the contamination of chernozem soils Pb and subsequent processes of its translocation in the system «soil – plant» have negative consequences and are manifested in the accumulation of toxicants in plants. It is significant that the largest metal-accumulating properties have cultivated early-ripening legumes, and the smallest – medium-ripe. It was determined that the indicators of Pb concentration in the storage organs of legume assimilants are influenced to a greater extent by the protein content in them than by mobile forms of Pb, which come due to translocation from soils contaminated with Pb. It is established that with the increase of protein in the organs of plant assimilators, the indicators of accumulation of toxic concentrations of Pb increase. Given that the genetic characteristics of chernozems allow us to consider them the most environmentally friendly soils in terms of anthropogenesis, however, they deposit contaminants and, accordingly, require optimization and development of detoxification methods. It has been experimentally established that when growing legumes of different vegetation varieties on chernozems contaminated with Pb, the intensity of their detoxification to obtain environmentally friendly plant products can be distributed as follows: $N_{180}P_{180}K_{180}$ + Pb + lime + manure > $N_{360}P_{360}K_{360}$+ Pb > $N_{180}P_{180}K_{180}$ + Pb + lime > $N_{180}P_{180}K_{180}$ + Pb + manure. The obtained laws provide an opportunity to develop recommendations and propose ways to detoxify contaminated Pb soils. Which will provide an opportunity to significantly reduce budget expenditures, which is socially necessary and cost-effective.

Keywords*: soils, chernozems, pollution, heavy metals, lead, detoxification methods, legumes.*

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Formulation of the problem. Ecological safety of soils and cultivation of ecologically safe food products of plant origin is one of the most urgent problems of today. Ensuring the environmental safety of food raw materials and food products is one of the main tasks that determine the health of the human population and the preservation of its gene pool. Up to 70 % of pollutants of various origins enter the human body from the environment with food. According to the World Health Organization, lead (Pb) is a global polluter that causes a large number of diseases [1]. The main strategy of the project developed by the UN «Health of the Nation in the fight against COVID – 19» is to reduce heavy metal intoxication that enters the human body with food [2]. The migration of Pb into food depends on many factors, among which the most important is the quality of the soil for growing food raw materials, which is used as an ingredient in food [3]. The absorption and accumulation of toxic concentrations of heavy metals in food raw materials are influenced by many factors, including the quality of soils, fertilizers, pesticides, precipitation and the ability of plants to bioaccumulate substances from the environment in which they are grown. Legumes have a great accumulating ability among plants, soybeans and chickpeas occupy leading positions in this chain [4]. In studies [5], it was determined that trace elements and heavy metals accumulate 90…97 % in legume cotyledons, and the content of native protein in the grain is directly proportional to the content of the accumulated substance. Given the fact that the source of toxic soil contamination on Pb are industrial enterprises, vehicle emissions, recycling plants and the fact that it belongs to the first class of danger – an important scientific and practical task is to conduct research under the system «soil – plant» with in order to develop methods of detoxification of soils on which cultivated plants are grown. It seems important to obtain patterns for determining the varieties of legumes (soybeans and chickpeas), which have the lowest bioaccumulative properties to the accumulation of lead through the process of translocation from soil to plants during their life cycle.

Analysis of recent research and publications. Toxic effects of Pb on human bodies have been confirmed by numerous clinical studies that have shown the negative effects of heavy metals on the nervous, cardiovascular, immune systems and oncology [6]. The work [7] is devoted to the development of detoxification techniques, in which scientists proposed to reduce the content of heavy metals in chernozems by detoxifying soils by growing battery plants on them, which will «extract» heavy metals from soils disinfecting them.

The disadvantage of the proposed technologies is the economic costs borne by farmers, producers and consumers. Farmers will suffer financial losses due to idle sown areas and the cost of seed. Producers will be forced to raise prices for the final food product as a result of reduced consumer purchasing power.

In the question [8] of studying the means of chemicalization for the accumulation of lead and zinc in potatoes, table beets and beans grown on chernozems is raised. Scientists have proven that the application of lime and the combined application of lime and manure reduce the accumulation of Pb in plants. It is determined that the most favorable for the bioaccumulation of heavy metals are beans.

Scientists have studied different groups of agricultural plants, which allowed us to determine only the group of plants that is most suitable for the accumulation of heavy metals from the soil. It is considered expedient to choose one group of plants of different vegetative varieties as the object of research, which makes it possible to establish optimal patterns during the development of detoxification methods.

A similar approach is described in [9], where scientists have studied different varieties of soybeans of the western ecotype. Scientists studied about 40 samples, and the results were optimized, which made it possible to eliminate the percentage of deviations and establish patterns with an error of up to 3 percent. The direction of the above research concerned only the influence of climatic conditions, and the issue of accumulation of heavy metals, in particular Pb in soybeans of different vegetation varieties was partially investigated.

In the work [10] where the chemical composition of legumes was studied, the issue of research of Pb content remained unresolved, the reason for this may be the difficulties associated with the complexity and financial importance of the experimental study.

Atomic absorption mass spectrophotometry is widely used for medical purposes to determine lead in urine. The method of atomic absorption spectrophotometry with electron-thermal atomization has been proposed for determination in beverages [11]. Each of the above methods is designed to determine lead, or in «Newtonian fluids» and is not suitable for the control of Pb in soybeans and chickpeas. When determining the lead content in metals or rocks, the method of direct polarography is used [12], but its use is appropriate only when the mass fraction of metal is significant, which provides a clear peak on the polarogram, and the content of related elements does not interfere with determination.

An option to overcome the above difficulties may be to use the method of inversion – voltammetry on a voltammetric analyzer «AVA», developed at the research and production enterprise «Burevesnik» (St. Petersburg, Russia). A significant advantage of the AVA analyzer is that this device can determine the mass fraction of Pb not only in different types of food, but also in feed, drugs and biological objects (blood, urine). The AVA analyzer is completely focused on the personal computer [13].

Selection of previously unsolved parts of the overall problem. To date, there are no in-depth studies to determine the nutritional value (protein, fats, carbohydrates) of soybeans and chickpeas of different vegetation varieties grown on Ukrainian chernozems. Taking into account the scientific results [14], where it is proved that the degree of accumulation of trace elements (in our case lead) in the grain during the growing season is influenced by the protein content in native grain, it is important to conduct the above studies. Which will scientifically substantiate the dependences on the protein content in the grain and the degree of accumulation of lead in it.

The mechanism of accumulation of Pb grains of soybeans and chickpeas of different vegetation varieties grown on contaminated Pb chernozems is little studied. The influence of nutrients (protein) in legumes in this process has not been scientifically substantiated.

Conducting experimental studies within the system «soil – plant» to determine the content of accumulated lead in soybeans and chickpeas of different vegetation varieties will establish patterns that will form the basis for developing a method of soil detoxification, which is certainly socially necessary and cost – effective because will preserve the health of human society, as a consequence of the state budget, which is intended for hospital care and disability benefits.

Formulation of the purpose of the article. The aim of the article is to determine ways to optimize lead-contaminated chernozem soils in the system «soil – plant» (on the example of chernozem soils within the test sites on the territory of the collection nursery «Agrotek» in Kyiv region).

To achieve this goal, the following tasks were set:

- to determine the indicators of Pb concentration in chernozem soils on test sites and storage bodies of legume assimilation (soybeans and chickpeas) with different protein content;
- to study the five-year dynamics of the content of protein, fats, carbohydrates in legumes grown on chernozem soils of the collection nursery «Agrotek» in the Kyiv region;
- to determine the indicators of lead concentration in soybeans and chickpeas of different vegetation varieties grown on chernozems, test sites of the collection nursery «Agrotek» in Kyiv region.

Presentation of the main research material. Experimental studies were conducted during 2019 – 2021 within the test sites on the territory of the collection nursery «Agrotek» in Kyiv region. There, biological material was selected for research – samples of legumes (soybeans and chickpeas) grown on chernozem soils. Ultra-early varieties were used for research: «Adamos», «Anastasia», «Annushka», «Alexandrit», «Bilyavka», «Vilshanka», «Vorskla», «Deni», «Elena», «Fairy» period of maturation) 75…85 days; early ripening: «Diamond», «Angelica», «Kyivska 98», «Phaeton», «Medea», «PSV 808», «Thanks», «Khortytsia», «South 30», «Rusa», PM 95…105 days; medium-early: «Artemis», «Delta», «Ivanka», «Tavria», «Golden», «Tavria 7», «Sprint», «Kharkiv», «Charm», «South 40», (PM 100…115 days); medium-ripe varieties «Agate», «Knight 50», «Colby», «Poltava», «Silver», «Success», «Masha», «Deimos», «Anna», «Podillya» (PM 115…125 days). Studies of the content of PFC in legumes were performed by ion exchange and liquid chromatography on a liquid chromatograph Shimadzu LC-20 (Japan).

Characteristics of samples of soybean and chickpea grains of different growing periods with determination of maximum and minimum yield during 3 years of research, are given in table 1.

During the experimental studies it was found

Table 1

Characteristics of legume samples (soybeans and chickpeas), selected within the test site of the collection nursery «Agrotek» (for the period 2019 – 2021)

Varieties legumes	Vegetation period, days	*Max* and *min* yield, tons per hectare
	Soy	
Ultra-early	75 – 85	3,3 – 3,5
Early ripening	95 – 105	3,3 – 3,6
Medium early	105 – 115	3,8 – 4,2
Medium ripe	115 – 125	4,1 – 4,6
	Chickpeas	
Early ripening	95 – 115	3,3 – 3,6
Medium ripe	115 – 125	3,8 – 4,2

that the periods of soybean and chickpea ripening ranged from 75 to 125 days, which is optimal for the climatic conditions of Ukraine. The study of four vegetation periods of soybean ripening and two vegetation periods of ripening of chickpea grains (late-ripening varieties of chickpeas with a ripening period of 180 – 220 days were considered irrelevant to study due to immaturity in Ukraine) allowed to conclude that yields for soybeans 2019–2021 were from 3,3 to 4,6 tons per hectare, chickpeas 3,3 to 4,2 tons per hectare, which indicates the high yield and favorableness of our climate zone for growing the above legumes.

The variability of nutrients, namely proteins, fats and carbohydrates in soybeans of different vegetation varieties grown on chernozems of the test site of the collection nursery «Agrotek» (2019 – 2021), are presented in table 2–5.

With the help of the MATLAB program, a mathematical model for the optimization of different varieties of soybeans grown on chernozems of the Kyiv region was created. The mathematical model is based on the results of research over 3 years, mathematically processed 200 indicators. Criteria for optimization: maximum amount of protein, minimum growing period, average fat and carbohydrate content. The above criteria were selected to determine the bioaccumulative properties of plants during the location of the pollutant in the system «soil – plant».

The obtained data (Tables 2–5) and the results of mathematical processing (Fig. 1 – 4) allow us to state that ultra-fast soybean varieties have an average protein content of 38,55%, fats – 17,90% of carbohydrates – 43,50% ; early ripening contains 42,75% protein, 14,50% fat and 42,75% carbohydrates.

However, medium-early are characterized by the following chemical composition – 37,40% protein, 20.50% fat, 42,10% carbohydrates; medium-ripe – 35,1% protein, 22,20% fat, 42,7 0% carbohydrates. It should be noted that the difference between the chemical composition of soybeans is probably due to different ripening periods, climatic

Table 2

Nutrient variability (PFC) of ultra-early soybean grains, grown on chernozems of the test site of the collection nursery «Agrotek» (Kyiv region, 2019–2021), %

№	Year of research	2019			2020			2021		
	Indexes (P – protein, F – fat, C – carbohydrate), %	P	F	C	P	F	C	P	F	C
1	Adamos	40,9	19,1	40,0	41,4	19,0	39,6	39,9	20,1	40,0
2	Anastasia	40,3	17,9	41,8	41,3	18,2	39,5	39,3	18,7	42,0
3	Annushka	37,9	18,0	44,1	38,4	16,9	44,7	40,9	17,9	41,2
4	Alexandrit	36,8	19,3	43,9	37,5	18,0	44,5	36,9	19,4	43,7
5	Bilyavka	37,9	18,7	43,4	37,3	17,2	45,5	38,0	18,0	44,0
6	Vilshanka	34,3	19,0	46,7	35,2	18,4	46,4	34,5	18,9	46,6
7	Vorskla	36,9	18,6	44,5	37,2	18,0	44,8	36,5	18,6	44,9
8	Deni	39,6	18,3	42,1	40,4	17,8	41,8	39,3	18,0	42,7
9	Elena	38,2	18,8	43,0	39,1	18,9	42,0	38,2	17,9	43,9
10	Fairy	39,4	18,1	42,5	40,3	16,9	42,8	39,2	18,0	42,8

Note: P – proteins, %; F – fat, %; C – carbohydrates %. (p> 0,5)

Table 3

Nutrient variability (PFC) of early ripening soybeans, grown on chernozems of the test site of the collection nursery «Agrotek» (Kyiv region, 2019–2021), %

№	Year of research	2019			2020			2021		
	Indexes (P – protein, F – fat, C – carbohydrate), %	P	F	C	P	F	C	P	F	B
1	Diamond	45,2	13,6	41,2	43,3	14,0	42,7	42,8	15,2	42,0
2	Angelica	41,9	13,8	44,3	42,9	13,1	44,0	41,6	12,7	45,7
3	Kyivska 98	40,3	16,2	43,5	41,4	17,0	41,6	41,2	16,8	42,0
4	Phaeton	41,2	14,9	43,9	42,9	13,9	43,2	41,4	14,2	44,6
5	Medea	42,0	15,6	42,4	41,8	15,1	43,1	42,0	14,4	43,6
6	PSV 808	40,9	15,4	43,7	41,9	14,1	44,0	41,0	13,8	45,2
7	Thanks	40,8	16,0	43,2	42,0	15,3	42,7	42,1	15,2	42,7
8	Khortytsia	43,9	12,0	44,1	43,5	11,9	44,6	41,9	11,9	46,2
9	South 30	43,9	13,1	43,0	43,9	12,9	43,2	42,0	13,9	44,1
10	Rusa	43,8	12,9	43,3	44,0	12,0	44,0	43,9	12,5	43,6

Note: P – proteins, %; F – fat, %; C – carbohydrates %. (p> 0,5)

Table 4

Nutrient variability (PFC) of medium-early soybeans, grown on chernozems of the test site of the collection nursery «Agrotek» (Kyiv region, 2019–2021), %

№	Year of research	2019			2020			2021		
	Indexes (P – protein, F – fat, C – carbohydrate), %	P	F	C	P	F	C	P	F	B
1	Artemis	36,9	20,1	43,0	35,9	19,6	45,5	36,4	19,8	43,8
2	Delta	35,0	21,3	43,7	34,6	20,1	45,3	35,9	19,9	44,2
3	Ivanka	36,5	18,9	44,6	36,4	18,7	45,2	36,9	19,3	43,8
4	Tavria	35,5	19,4	45,1	35,2	19,1	45,7	35,9	19,9	44,2
5	Golden	38,8	18,5	42,7	39,9	18,6	41,5	39,6	18,8	41,6
6	Tavria 7	39,3	18,9	41,8	38,9	18,3	42,8	38,2	19,2	42,6
7	Sprint	35,0	22,6	42,4	34,6	20,8	44,6	35,4	20,9	43,7
8	Kharkiv	37,9	20,9	41,2	36,2	21,0	42,8	37,0	20,7	42,3
9	Charm	37,2	22,4	40,4	37,5	21,9	40,6	36,9	21,7	41,4
10	South 40	35,0	21,9	43,1	34,9	22,0	43,1	35,0	22,1	42,9

Note: P – proteins, %; F – fat, %; C – carbohydrates %. (p> 0,5)

Table 5

Nutrient variability (PFC) of medium-ripe soybeans, grown on chernozems of the test site of the collection nursery «Agrotek» (Kyiv region, 2019–2021), %

№	Year of research	2019			2020			2021		
	Indexes (P – protein, F – fat, C – carbohydrate), %	P	F	C	P	F	C	P	F	B
1	Agate	33,9	23,8	42,3	33,8	23,9	42,3	33,9	23,1	43,0
2	Knight 50	34,0	23,9	42,1	33,9	23,7	42,4	34,6	23,3	42,1
3	Colby	36,6	22,1	41,3	33,3	22,1	41,6	36,4	22,6	41,0
4	Poltava	34,9	23,7	41,4	34,2	23,5	42,3	34,8	23,9	41,3
5	Silver	34,4	21,1	44,5	34,7	21,9	43,4	33,9	22,4	43,7
6	Success	35,2	21,3	43,5	35,6	21,5	42,9	36,0	21,9	42,1
7	Masha	39,9	22,9	43,2	34,5	23,1	42,4	33,9	23,3	42,8
8	Deimos	36,3	20,4	43,3	35,9	21,0	43,1	35,5	21,2	43,3
9	Anna	33,7	22,9	43,4	33,3	22,4	44,3	33,2	21,6	45,2
10	Podillya	34,9	22,6	42,5	34,0	21,9	44,1	33,9	22,1	44,0

Note: P – proteins, %; F – fat, %; C – carbohydrates %. (p> 0,5)

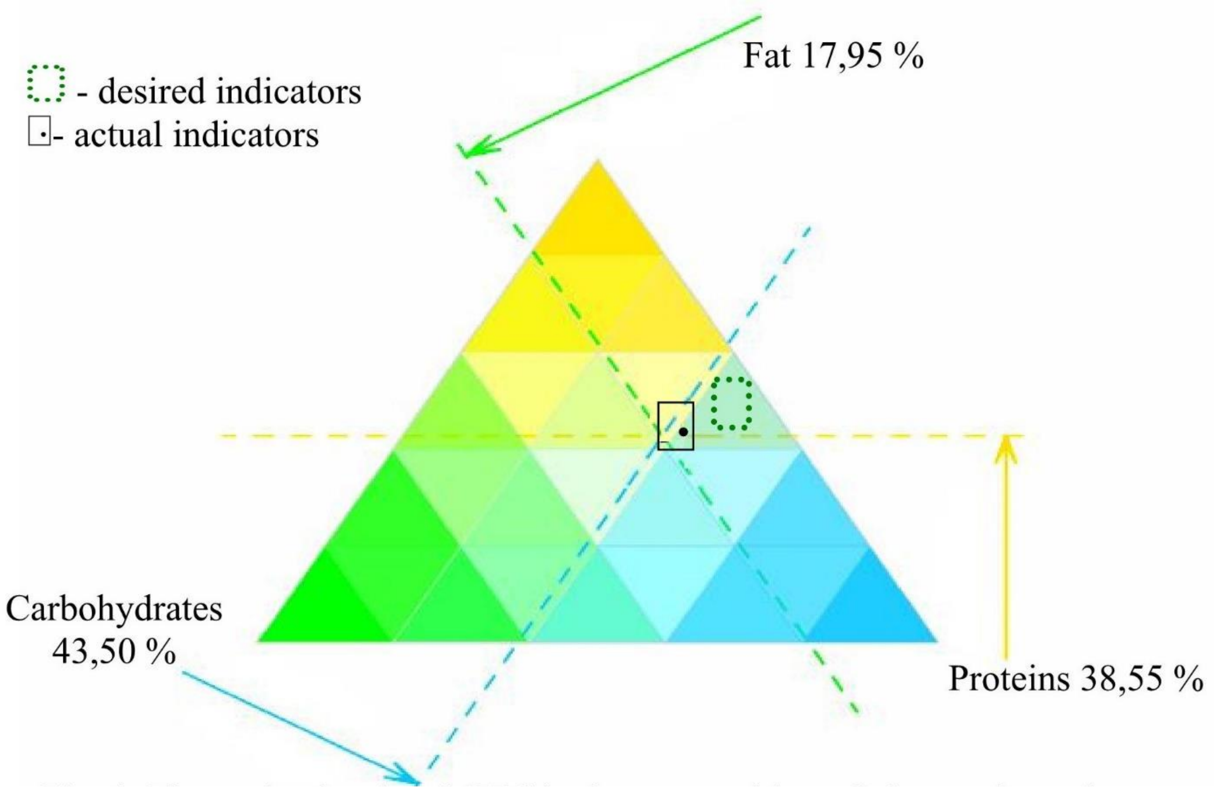

Fig. 1. The optimal ratio of PFC in the composition of ultra-early soybean varieties, %

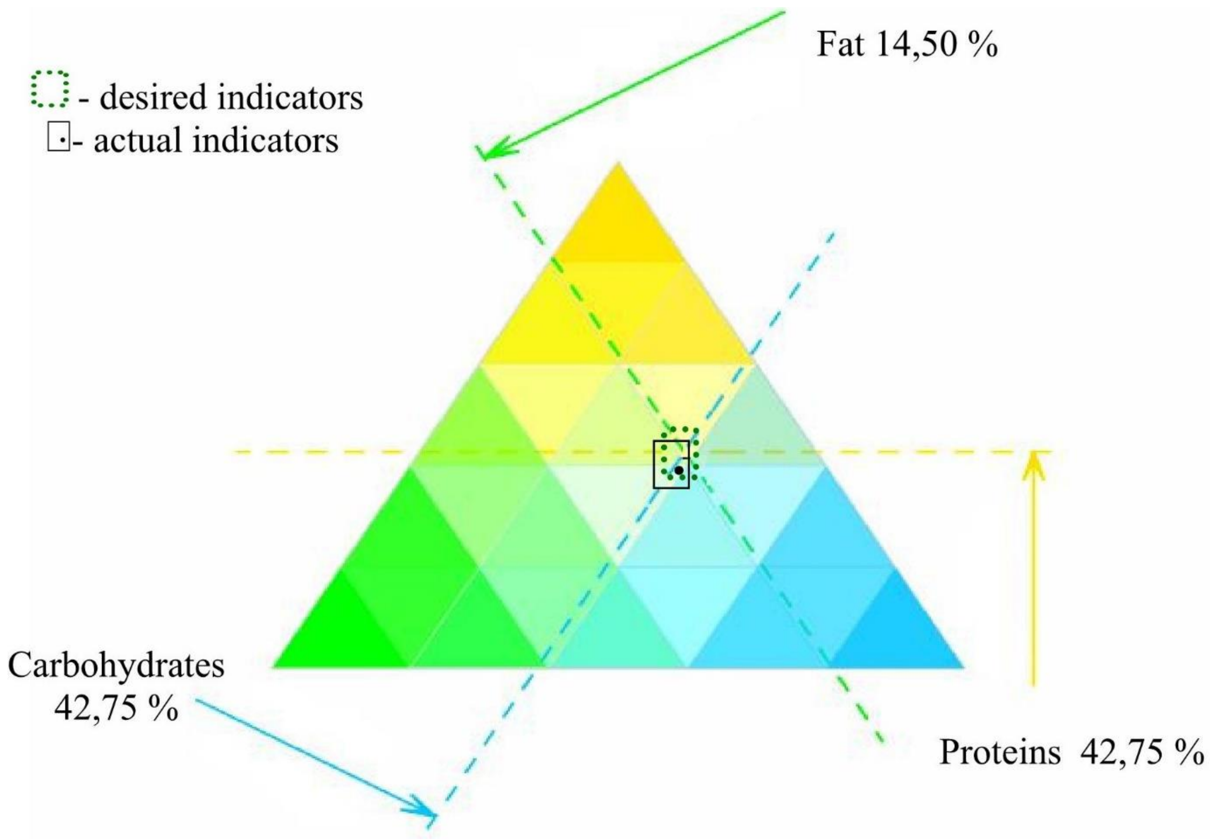

Fig. 2. The optimal ratio of PFC in the composition of early soybean varieties, %

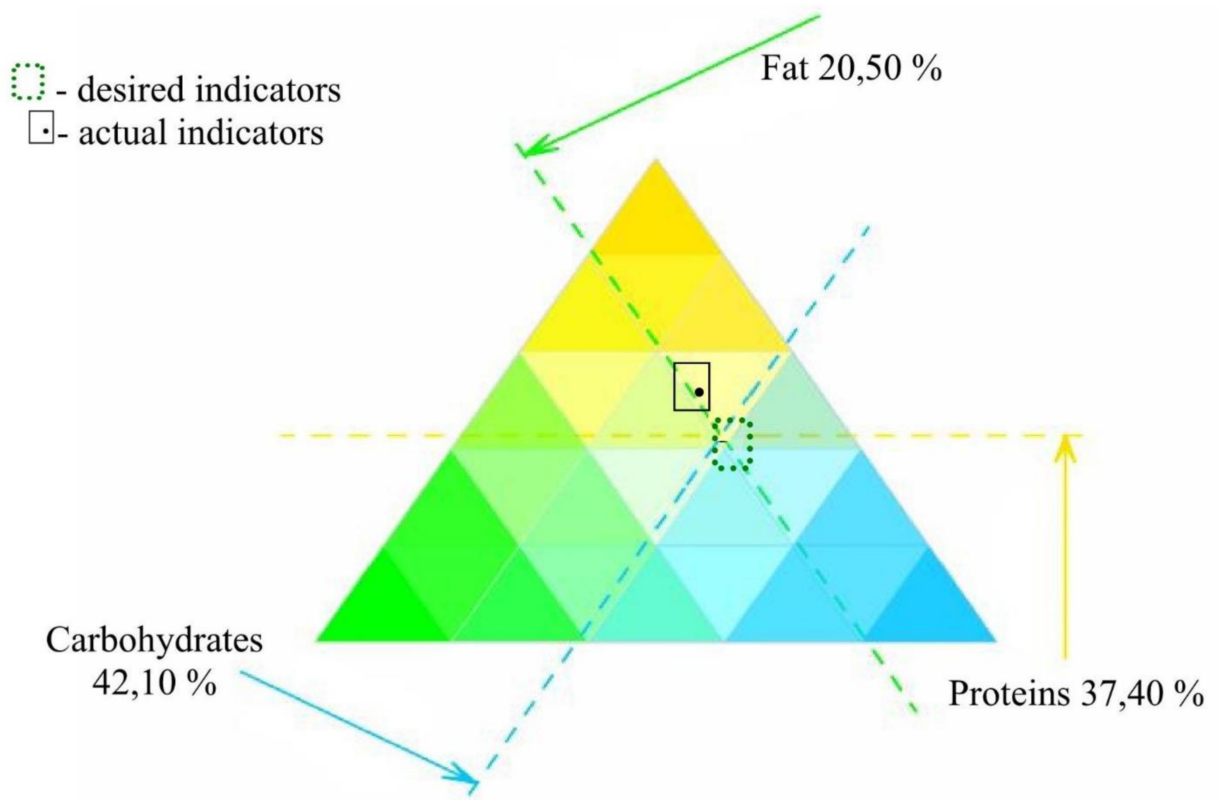

Fig. 3. The optimal ratio of PFC in the composition of medium-early soybean varieties, %

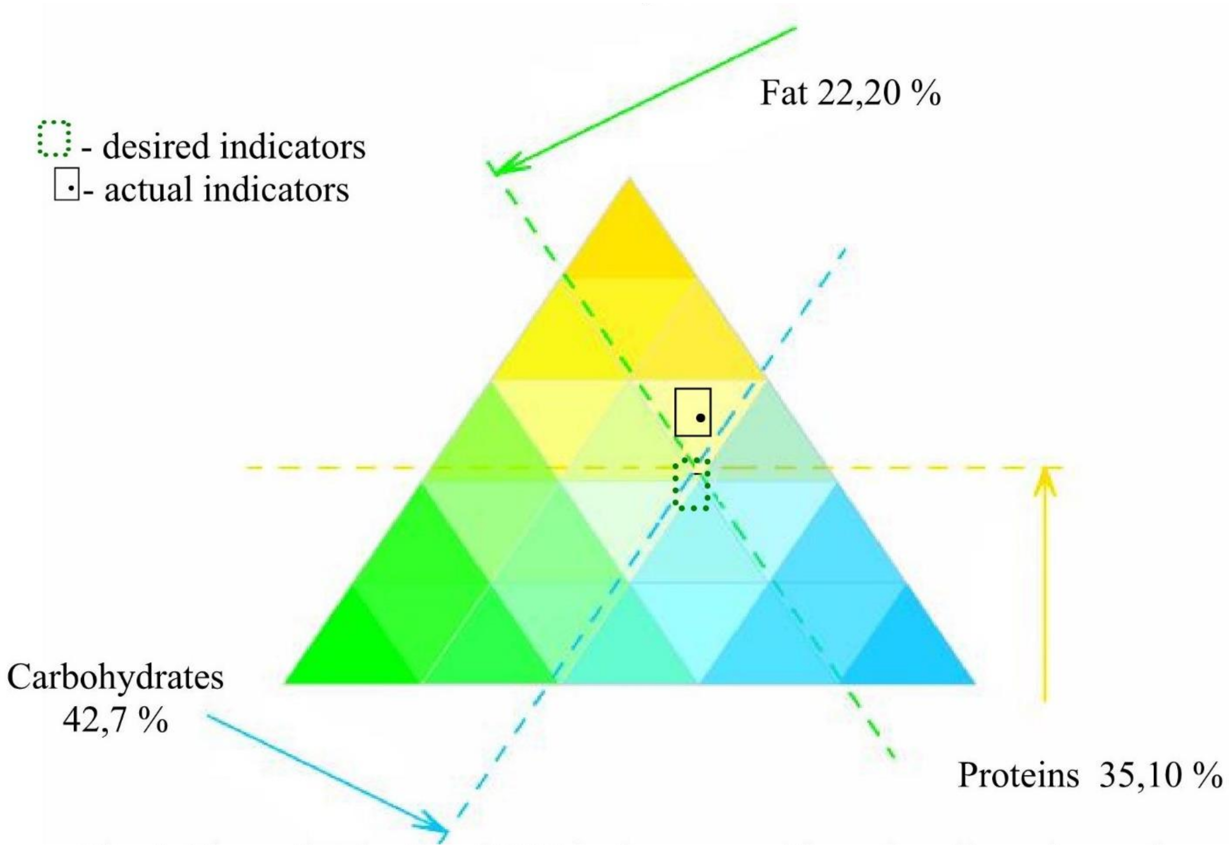

Fig. 4. The optimal ratio of PFC in the composition of medium-ripe soybean varieties, %

factors (number of hot and rainy days), which significantly affect the chemical composition of legumes. Early soybean varieties (42,75% protein, 14,50% fat, 42,75% carbohydrates) and a short growing season (up to 95…105 days) have the maximum protein content. It should be noted that the growing period is an important indicator given the economic benefits for the «manufacturer», which is not imposed on winter crops and, as a consequence, to idle sown areas.

Ultra-early soybean varieties are 4,2% inferior to early-maturing soybeans in terms of protein content, medium-early and medium-ripening varieties are 5,35% and 7,65% lower, respectively. In terms of fat and carbohydrate content, medium-early and medium-ripe ones do not differ significantly, but have a difference of 10…15 days between the period of bean ripening. In the table 6-7 presents the results of studies of variability of nutrients, namely proteins, fats and carbohydrates in chickpea grains of different vegetation varieties grown on chernozems of the test site of the collection nursery «Agrotek» for the period 2019 – 2021. The optimal ratio of PFC in the composition of chickpea varieties grown on chernozems of the Kyiv region are shown in Fig. 5–6.

Table 6

Nutrient variability PFC of early ripe chickpea grains, grown on chernozems of the test site of the collection nursery «Agrotek» (Kyiv region, 2019–2021), %

№	Year of research	2019			2020			2021		
	Indexes (P – protein, F – fat, C – carbohydrate), %	P	F	C	P	F	C	P	F	B
1	Hyatt	22,9	16,5	60,6	22,3	16,7	61,0	23,4	16,0	60,6
2	Erdem	16,5	24,9	58,6	16,0	22,9	61,1	16,7	24,2	59,1
3	Star World	24,7	15,4	59,9	23,4	15,8	60,8	23,5	16,0	60,5
4	Elite	22,1	16,6	61,3	22,0	16,9	61,1	22,2	16,5	61,3
5	Ecord	21,4	15,8	62,8	21,2	15,7	63,1	19,9	15,5	64,6
6	Alexandrite	21,1	17,2	61,7	19,9	17,6	62,5	19,8	17,7	63,2
7	Rosana	22,6	15,8	61,6	22,0	15,7	62,3	21,9	16,2	61,9
8	Edda	27,3	21,4	51,3	27,3	21,4	51,3	27,3	21,4	51,3
9	Lamb's Horn	21,3	16,9	61,8	20,3	16,4	63,3	21,7	17,0	61,3
10	Lilac	21,6	15,5	62,9	21,9	15,9	62,2	21,5	16,0	62,5

Note: P – proteins, %; F – fat, %; C – carbohydrates %. (p> 0,5)

Table 7

Nutrient variability PFC of medium-ripe chickpea grains, grown on chernozems of the test site of the collection nursery «Agrotek» (Kyiv region, 2019–2021), %

№	Year of research	2019			2020			2021		
	Indexes (P – protein, F – fat, C – carbohydrate), %	P	F	C	P	F	C	P	F	B
1	Vector	19,3	15,1	65,6	19,8	15,0	65,2	19,3	15,7	65,0
2	Boyarinya	20,2	15,0	64,8	20,7	14,6	64,7	20,9	14,3	64,8
3	Budzhak	20,2	15,9	63,9	19,6	16,4	64,0	19,1	16,2	64,7
4	Anatoly	17,9	14,0	68,1	17,4	13,4	69,2	17,8	13,6	68,6
5	European	15,2	19,2	65,6	15,7	19,5	64,8	15,9	19,7	64,4
6	South-East	15,6	16,7	67,7	15,4	16,2	68,4	15,9	16,8	67,3
7	Gypsy	16,5	17,6	65,9	15,2	16,9	67,9	16,4	17,8	65,8
8	Jubilee/k-2405	14,5	15,4	70,1	14,8	15,2	70,0	14,3	14,9	69,9
9	Bashkir	19,9	16,8	63,3	19,3	16,6	64,1	19,2	16,1	64,7
10	Flower	20,2	15,6	64,2	20,2	15,9	63,9	20,2	16,0	63,8

Note: P – proteins, %; F – fat, %; C – carbohydrates %. (p> 0,5)

The objects of the study were twenty varieties of chickpeas of different growing season. Varieties with early and medium ripening matures were studied. The following varieties of chickpeas were used during the study: «Hyatt», «Erdem», «Star World», «Elite», «Ecord», «Alexandrite», «Rosana», «Edda», «Lamb's Horn», «Lilac» growing period 95…115 days, and medium-ripe sot chickpeas:

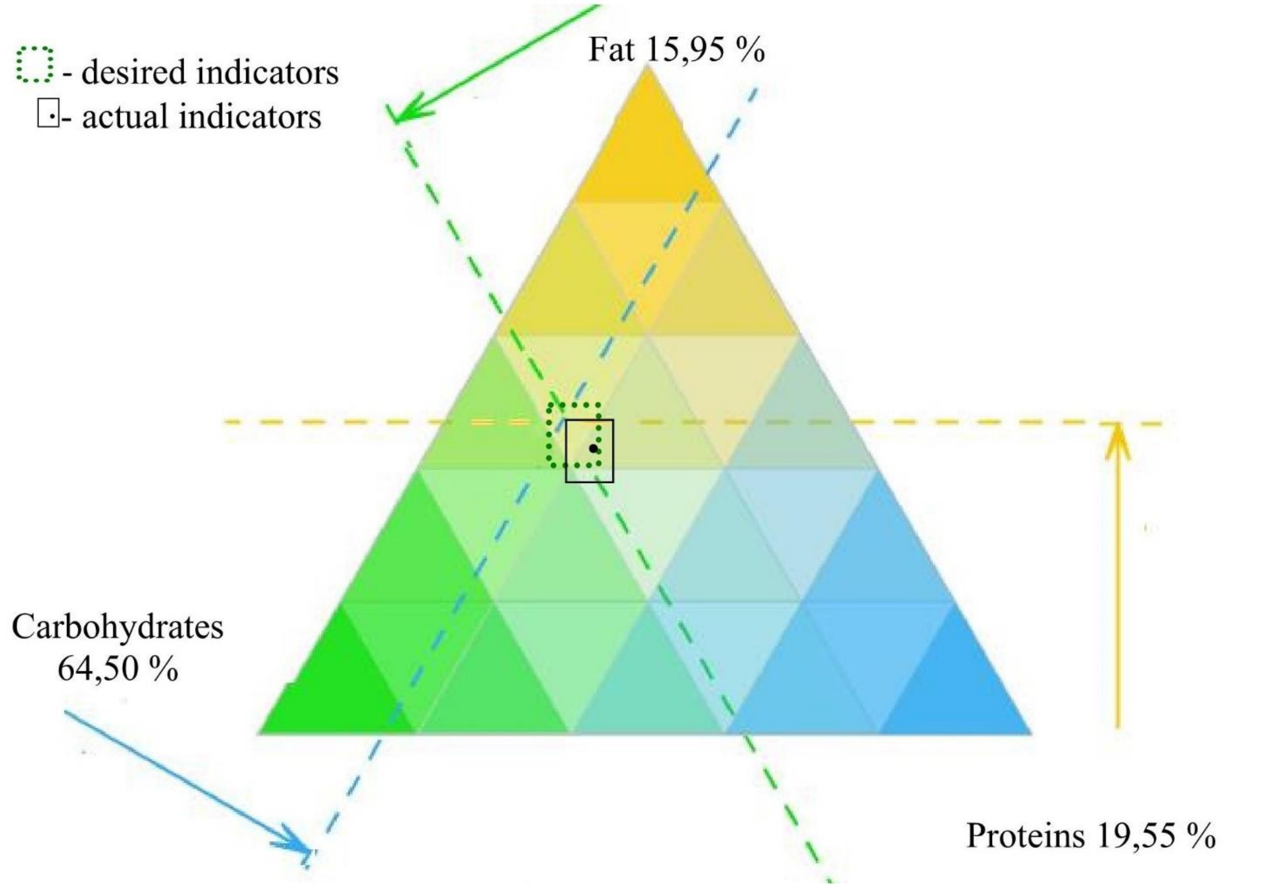

Fig. 5. The optimal ratio of PFC in the composition of early varieties of chickpeas, %

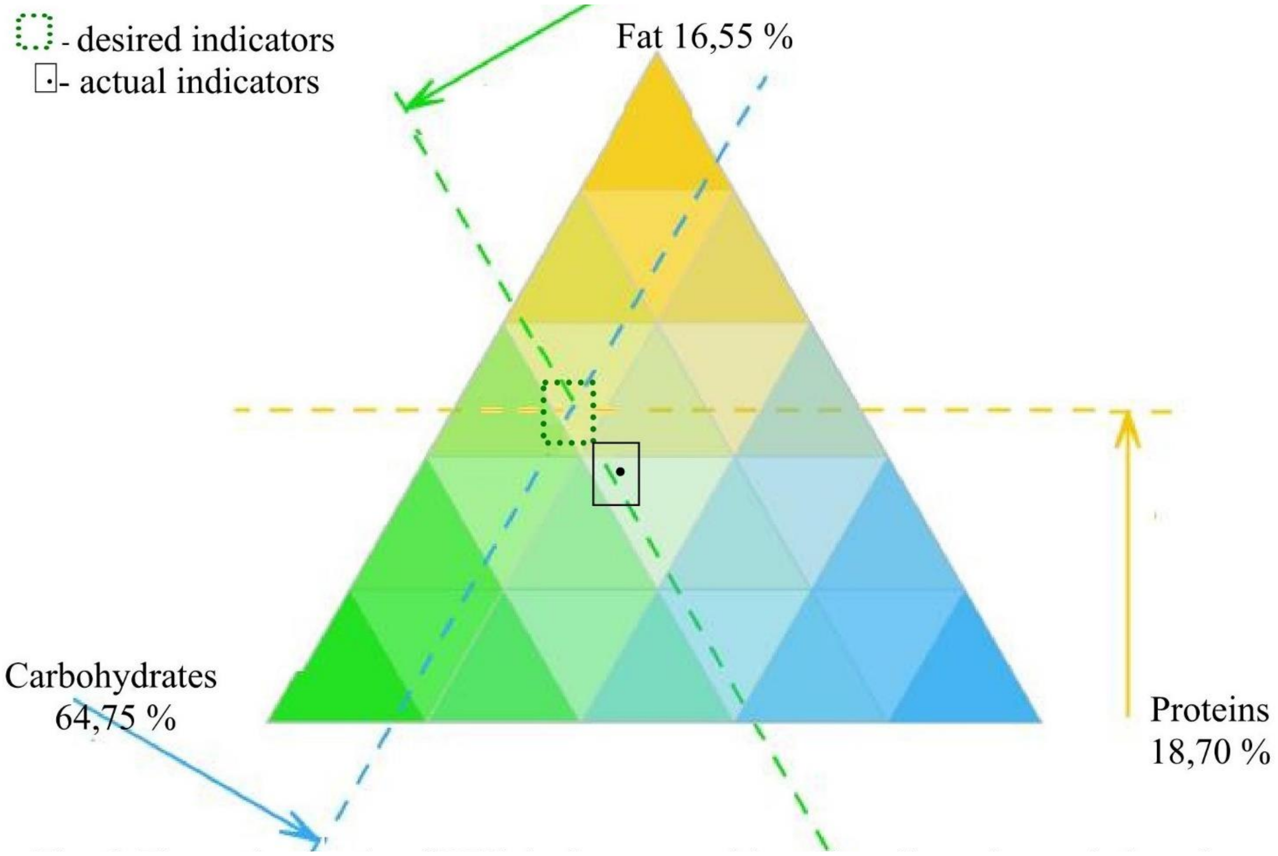

Fig. 6. The optimal ratio of PFC in the composition of medium-ripe varieties of chickpeas, %

«Vector», «Boyarinya», «Budzhak», «Anatoly», «European», «South-East», «Gypsy», «Jubilee/k-2405», «Bashkir», «Flower», growing period 115…125 days.

The results of the research were mathematically processed and optimized according to the criteria that were dominant during the research with soybeans (*max* amount of protein, *min* growing period, average fat and carbohydrate content).

As a result of the study it was found that the protein content in chickpea grains is much lower than the protein content in soybeans, according to [15], it is based in the range from 13 to 24%. It was experimentally determined that the optimal ratio in terms of protein content has early-ripening varieties of chickpeas (19,55%), fats – 15,95%, carbohydrates – 64,5%. Medium-ripe varieties of chickpeas have – 18,7% protein, 15,95% fat and 64,75% carbohydrates.

From the experiment it is possible to conclude that as an object of study to establish the dependencies on the protein content in grain and the degree of accumulation of lead in it from the soil on which legumes are grown, the most interesting are early-maturing soybean and chickpea varieties 5,35 and 0,85% (respectively), and during the growing season ripen 20 – 25 days earlier.

The next stage of the study was to determine the Pb content in the grains of early-maturing soybean and chickpea varieties with different PFC content. The objects of the study were soybean variety: «Diamond» (44,2% protein content, 13,4% fat content, 42,4% carbohydrate content) with the maximum protein content and early-maturing soybean variety «South 30» (30,1% protein content, 17,7% fat content, 52,2 % carbohydrate content) with a minimum protein content. Early-ripening chickpea variety «Edda» (27,3 % protein content, 21,4% fat content, 51,3 % carbohydrate content) with the maximum protein content and early-ripening chickpea variety «Erdem» (16,7% protein content – 24,2 % fat content, 59,1% carbohydrate content) with a minimum protein content. Experimental studies were conducted on the basis of the State Institution «Scientific Center for Preventive Toxicology, Food and Chemical Safety named after Academician LI Bear of the Ministry of Health of Ukraine» by the method of inversion-voltammetry using a voltammetric analyzer «AVA-3» which is equipped with an indicator electrode for the determination of lead. The results of the study are presented in table 8 and fig. 7.

Table 8

Indicators of Pb concentration in chernozems and early ripening grains varieties of soybeans and chickpeas with different protein content

Objects of research	Early-maturing varieties of soybeans		Early ripening varieties of chickpeas	
	Diamond	South 30	Edda	Erdem
	Protein 42,2%	Protei 30,1%	Protein 27,3%	Protein 16,7%
Mass fraction of Pb, µ/kg				
Chernozem, (before sowing legumes)	7,24±0,04	6,52±0,04	7,88±0,04	10,17±0,04
Chernozem (after harvest)	6,96±0,05	5,93±0,05	7,44±0,05	9,72±0,05
Bean grain (seed material)	0,34±0,004	0,31±0,002	0,30±0,004	0,27±0,002
Legumes (harvest)	0,41±0,003	0,39±0,003	0,38±0,005	0,32±0,003

It was experimentally established that the mass fraction of Pb in chernozem at the test site of the collection nursery «Agrotek» in the Kyiv region before sowing legumes was in the range from 6,52 to 10,17 µ/kg. After harvesting legumes, there is a decrease in lead content in the soil by 0,45 – 0,59 µ/kg.

An increase in the mass fraction of Pb in grains from the yield compared to seed material by 0,07 and 0,08 µ/kg in soybean varieties «Diamond» and «South – 30» (respectively) and by 0,8 and 0,05 µ/kg in the varieties «Edda» and «Erdem» (respectively). Sample B – visualizes the content (accumulation on the surface of the electrode) of lead in the early-ripening variety of chickpeas (harvest) «Erdem», protein content of 16,7%. On experimental sample A – visualized lead content in early-maturing soybean variety «Diamond», protein content 42,2%.

Analyzing experimental studies (Table 8 and Fig. 7), it is possible to conclude that the accumulation of Pb in legumes is significantly affected by the protein content in the grain. It is known [16] that one of the main ways of moving mobile forms of heavy metals to the plant is the process of their location from the soil and absorption by plant roots. Plants and their storage organs of assimilates are ab-

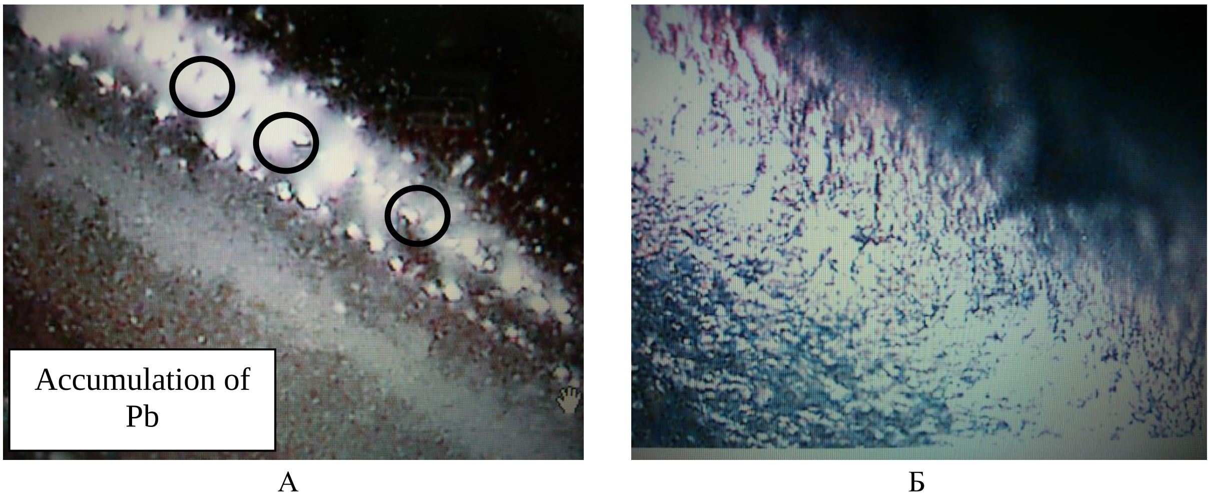

Fig. 7. Accumulation of Pb on the surface of the working electrode of the ABA-3 analyzer in grains of early-ripening varieties of soybean and chickpeas with different contents protein, (1000 times magnification):
A – early-ripening soybean variety «Diamond», protein content 42,2%; B – early-ripening variety of chick-peas «Erdem» protein content of 16,7%

le to accumulate Pb during the growing season, where the process of accumulation with protein takes place, and the concentration of Pb depends on the protein content. The obtained experimental studies are reflected in [17], where it is substantiated that heavy metals entering the plant from the soil through the root system are actively moved metabolically or by diffusion processes in contact with cell walls and a number of mineral and organic compounds contained in cells. Scientists have proven [18] that the uptake of heavy metals by plants and their subsequent accumulation along the food chain is a potential threat to human and animal health. This leads to mass degradation of Ukrainian chernozems concentrated in areas with developed industry. Also, a specific feature of soil contamination with heavy metals is a very low rate of soil self-cleaning. As for Pb, its high concentrations in the soil lead to degradation and reduction of the number and diversity of soil microbiocenoses. Based on the above, it is important to study the concentration of Pb in soybeans and chickpeas depending on the chemical composition of soils for cultivation. The results of experimental studies are given in table 9–10.

Lime and manure were selected for joint application to reduce the concentration of lead in the soil for joint application to test plots with chernozem soils. The research was conducted according to the following scheme:

Site control (without fertilizers and artificial application of Pb);

$N_{180}P_{180}K_{180}$;

$N_{180}P_{180}K_{180}$ + Pb;

N1$_{80}P_{180}K_{180}$ + lime (4 t/ha) + Pb;

$N_{180}P_{180}K_{180}$ + manure (50 t/ ha) + Pb;

$N_{180}P_{180}K_{180}$ + lime (4 t/ha) + manure (50 t/ha) + Pb;

$N_{360}P_{360}K_{360}$ + Pb.

Agrochemical parameters of the experimental site: humus content – 5,8%, pHKl – 5,6, mobile phosphorus – 312 mg/kg, metabolic potassium – 173 mg/kg, nitrogen – 175 mg/kg, lead – 21,5 mg/kg. The area of the experimental plot is 10,5 m^2. Heavy metals in concentrations: Pb (CH3COO) 2 * Pb (OH) 2 (82,0 g/m^2), each made separately, premixed with soil. Analysis of the content of Pb was determined using the method of inversion voltammetry.

The results of experimental studies showed that the lowest concentration of Pb in soybeans obtained from plants grown on lead-contaminated soils was obtained in areas using lime, manure and mineral fertilizers – scheme $N_{180}P_{180}K_{180}$ + Pb + lime + manure.

Experimental areas with lead-contaminated chernozems, where a double dose of mineral fertilizers and manure was used, have the same tendency to accumulate toxic metal in soybean cotyledons.

Less impact on the detoxification process than a double dose of mineral fertilizers – scheme $N_{360}P_{360}K_{360}$ + Pb and manure – scheme $N_{180}P_{180}K_{180}$ + Pb + manure, has an introduction into artificially contaminated lead soil – lime (scheme $N_{180}P_{180}K_{180}$ + Pb + lime).

The results of research on the concentration of lead in chickpea grains of different vegetation varieties depending on the chemical composition of soils are given in table 10.

It has been experimentally proven that changes in the chemical composition of the soil affect the accumulation of lead in the storage organs of soy and chickpea assimilators. It was found that the intensity of Pb accumulation decreases with the com-

Table 9

The concentration of Pb in soybeans of different varieties depending on the chemical composition of soils

Formula chemical composition of soils	Ultra-early varieties of soybeans, (75...85 days)	
	Adamos	Anastasia
Control	0,47±0,002	0,48±0,004
$N_{180}P_{180}K_{180}$	0,46±0,003	0,47±0,002
$N_{180}P_{180}K_{180}$ + Pb	0,70±0,002	0,70±0,003
$N_{180}P_{180}$K180 + Pb + lime	0,69±0,001	0,62±0,002
$N_{180}P_{180}K_{180}$ + Pb + manure	0,51±0,002	0,53±0,002
$N_{180}P_{180}K_{180}$ + Pb + lime + manure	0,42±0,003	0,45±0,001
$N_{360}P_{360}K_{360}$+ Pb	0,49±0,002	0,47±0,002
Formula chemical composition of soils	Early-maturing varieties of soybeans, (95...105 days)	
	Diamond	South 30
Control	0,50±0,003	0,50±0,003
$N_{180}P_{180}K_{180}$	0,49±0,001	0,48±0,003
$N_{180}P_{180}K_{180}$ + Pb	0,73±0,002	0,75±0,002
$N_{180}P_{180}$K180 + Pb + lime	0,64±0,004	0,68±0,002
$N_{180}P_{180}K_{180}$ + Pb + manure	0,59±0,002	0,57±0,004
$N_{180}P_{180}K_{180}$ + Pb + lime + manure	0,33±0,002	0,32±0,002
$N_{360}P_{360}K_{360}$+ Pb	0,41±0,002	0,42±0,001
Formula chemical composition of soils	Medium-ripe varieties of soybeans (115...125 days)	
	Agate	Silver
Control	0,42±0,002	0,41±0,004
$N_{180}P_{180}K_{180}$	0,43±0,003	0,44±0,002
$N_{180}P_{180}K_{180}$ + Pb	0,64±0,002	0,61±0,003
$N_{180}P_{180}$K180 + Pb + lime	0,6±0,001	0,62±0,002
$N_{180}P_{180}K_{180}$ + Pb + manure	0,49±0,002	0,50±0,002
$N_{180}P_{180}K_{180}$ + Pb + lime + manure	0,39±0,003	0,40±0,001
$N_{360}P_{360}K_{360}$+ Pb	0,43±0,002	0,45±0,002

Table 10

The concentration of Pb in chickpea of different varieties depending on the chemical composition of soils

Formula chemical composition of soils	Early ripening varieties of chickpeas, (95...115 days)	
	Edda	Erdem
Control	0,41±0,004	0,40±0,001
$N_{180}P_{180}K_{180}$	0,40±0,002	0,40±0,004
$N_{180}P_{180}K_{180}$ + Pb	0,53±0,003	0,52±0,003
$N_{180}P_{180}$K180 + Pb + lime	0,49±0,001	0,47±0,002
$N_{180}P_{180}K_{180}$ + Pb + manure	0,45±0,003	0,46±0,004
$N_{180}P_{180}K_{180}$ + Pb + lime + manure	0,21±0,002	0,25±0,003
$N_{360}P_{360}K_{360}$+ Pb	0,29±0,001	0,27±0,003
Formula chemical composition of soils	Medium-ripe varieties of chickpeas, (115...125 days)	
	Bashkir	Flower
Control	0,40±0,002	0,38±0,002
$N_{180}P_{180}K_{180}$	0,38±0,001	0,38±0,001
$N_{180}P_{180}K_{180}$ + Pb	0,51±0,002	0,50±0,003
$N_{180}P_{180}$K180 + Pb + lime	0,43±0,003	0,45±0,004
$N_{180}P_{180}K_{180}$ + Pb + manure	0,46±0,002	0,44±0,004
$N_{180}P_{180}K_{180}$ + Pb + lime + manure	0,28±0,0024	0,29±0,003
$N_{360}P_{360}K_{360}$+ Pb	0,31±0,002	0,34±0,003

bined use of mineral fertilizers, lime and manure. The use of one lime does not significantly affect the detoxification process.

According to the intensity of detoxification of soybeans and chickpeas of different vegetation varieties during cultivation on chernozems contaminated with lead, can be distributed as follows:

$N_{180}P_{180}K_{180}$ + Pb + lime + manure > $N_{360}P_{360}K_{360}$ + Pb > $N_{180}P_{180}K_{180}$ + Pb + manure > $N_{180}P_{180}K_{180}$ + Pb + lime.

It is hypothesized that the periods of maturation (the number of days for which the grain matures from seed to fruit) in lead-contaminated soils does not affect the increase in the concentration of Pb in the grain of legumes. The relationship between protein content in grain and Pb concentration indicators has been established. Soybean and chickpea varieties with the lowest protein content, namely medium-ripe, are not very suitable for accumulation. A similar result of experimental studies is given in [19-20], which describes the process of germination of chickpeas in a solution of sodium hydrosulphite ($NaHSeO^3$). Studies have shown the distribution of selenium by the anatomical parts of the sprouted grain and proved that in the composition of the sprouted grain of chickpeas 95…99% of selenium is in the cotyledon, we assume that in the protein fraction. This indicates a high degree of conversion of selenium into organic form during germination in $NaHSeO^3$ solution.

The performed research provided an opportunity to determine ways to optimize lead-contaminated chernozem soils in the «soil – plant» system (on the example of chernozem soils within test sites on the territory of the collection nursery «Agrotek» in Kyiv region). The obtained research results are important for solving environmental problems of various profiles. Which is socially necessary and economically beneficial, because it will preserve the health of the population.

Conclusions. Experimental studies were conducted at the test site within the collection nursery «Agrotek» in the Kyiv region. It was experimentally established that the mass fraction of artificially introduced into the chernozem soil before sowing legumes was in the range from 6,52 to 10,17 μ/kg. After harvesting legumes, a decrease in the concentration of Pb in the soil to 0,45…0,59 μ/kg was observed. Indicators of lead concentration in soybean and chickpea grains with maximum and minimum protein content were also studied. An increase in the mass fraction of lead in grains from the harvest compared to seed material by 0,07 and 0,08 μ / kg in soybean varieties «Diamond» and «South – 30» (respectively) and by 0,08 and 0,05 μ / kg in the varieties «Edda» and «Erdem» (respectively).

Indicators of Pb concentration in soybean and chickpea grains depending on the chemical composition of soils as an experimental medium for growing legumes were determined. It was found that the lowest concentration of lead in soybeans and chickpeas on lead-contaminated soils was obtained in areas where lime, manure and mineral fertilizers were used. Legumes obtained from plants grown in artificially contaminated lead test areas, where a double dose of mineral fertilizers and manure was used, have the same tendency to accumulate toxicant. The intensity of lead accumulation by legumes is not affected by the length of the growing season of plants growing on lead-contaminated soils, but is significantly affected by the protein content in the grain, which increases the concentration of lead. Early-ripening varieties have the highest bioaccumulating ability, and medium-ripening soybean and chickpea varieties have the lowest. According to the intensity of detoxification of soybean and chickpea grains of different vegetation varieties during the growing season, grown on chernozems artificially contaminated with lead, can be distributed as follows: $N_{180}P_{180}K_{180}$ + Pb + lime + manure > $N_{360}P_{360}K_{360}$+ Pb > $N_{180}P_{180}K_{180}$ + Pb + lime > $N_{180}P_{180}K_{180}$ + Pb + manure.

Studies of protein, fat, carbohydrates in soybeans and chickpeas of different vegetation varieties over a five-year period grown on chernozem soils of the test site showed that ultra-fast soybean varieties have an average protein content of 38,55%, fat – 17,90% of carbohydrates – 43,50%; early ripening contains 42,75% protein, 14,50% fat and 42,75% carbohydrates. However, medium-early are characterized by the following chemical composition – 37,40% protein, 20,50% fat, 42,10% carbohydrates; medium-ripe – 35,1% protein, 22,20% fat, 42,70% carbohydrates. The study of the content of protein, fats, carbohydrates in chickpea grains of different vegetation varieties made it possible to establish that early-ripening varieties of chickpeas have an average protein content of 19,55%, fats – 15,95%, carbohydrates – 64,5%. Medium-ripe varieties of chickpeas have an average protein content of 18,7% protein, 15,95% fat and 64,75% carbohydrates.

Experimental studies have shown that early maturing varieties of legumes are of the greatest interest for establishing the relationships in test plants between the protein content of legumes and Pb concentration (due to translocation processes from the soil on which plants are grown and bioaccumulation).

The results of research are important for solving environmental problems of various profiles, because the results highlight the patterns of determining the impact of heavy metals on environmental components, methods of detoxification of chernozem soils, environmentally friendly plant products, food safety and, consequently, people's health. All this is socially necessary and economically beneficial, because it will preserve the health of the population and save the state budget funds allocated for hospital care.

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Authors Contribution: All authors have contributed equally to this work

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Пути оптимизации загрязненных свинцом черноземных почв в системе почва – растение

***Яна Александровна Белецкая*[1],**
к. т. н., доцент, кафедра международной электронной коммерции
и гостинично-ресторанного дела,
[1]Харьковский национальный университет имени В.Н. Каразина,
пл. Свободы, 4, г. Харьков, 61022, Украина;
***Алла Наумовна Некос*[1],**
д. геогр. н., профессор, кафедра экологической безопасности и экологического образования;
***Анастасия Бехтер*[2],**
аспирант, секретарь кафедры экологической биотехнологии,
[2]Лодзинский технологический университет,
ул. Политехника 3Б, 605, г. Лодзь, Польша, 90-535;
***Анна Сергеевна Кривцова*[1],**
к. экон. н., кафедра международной электронной коммерции и гостинично-ресторанного дела;
***Ольга Ивановна Брайнингер*[3],**
аспирант, [3]Государственный биотехнологический университет,
ул. Алчевских, 44, г. Харьков, Украина, 61002

Экологическая безопасность почв и выращивание экологически безопасных пищевых продуктов растительного происхождения является одной из наиболее актуальных проблем современности. Обеспечение экологической безопасности продовольственного сырья и пищевых продуктов является одной из главных задач, определяющих здоровье популяции человека и сохранение его генофонда. С пищей в организм человека из окружающей среды поступает до 70% загрязняющих веществ разного происхождения. По данным Всемирной организации здравоохранения, свинец (Pb) является глобальным загрязнителем, который вызывает большое количество заболеваний. Основная стратегия разработанного в ООН проекта «Здоровье нации в борьбе с COVID-19» заключается в уменьшении интоксикации тяжелыми металлами, поступающими в организм с пищей. В статье представлены результаты исследования путей оптимизации загрязненных на свинец черноземных почв в системе «почва – растение». Объектами исследования были вариации сои и нута разных сортов растительности. Исследовано содержание белка, жиров, углеводов в зернах сои и нута разных вегетационных сортов за период 3 лет, выращенных на черноземах Киевской области. Изучено содержание свинца в зернах сои и нута с максимальным и минимальным содержанием белка. Научно обоснован процесс аккумуляции свинца зернами сои и нута в зависимости от состава почв для выращивания. Установлено, что по интенсивности детоксикации зерен сои и нута различных вегетационных сортов при выращивании на черноземах загрязненных свинцом можно распределить следующим образом:: $N_{180}P_{180}K_{180}$+ Pb + известь + навоз > $N_{360}P_{360}K_{360}$+ Pb > $N_{180}P_{180}K_{180}$+ Pb + навоз > $N_{180}P_{180}K_{180}$+ Pb + навоз.

Полученные результаты исследований важны для научного сообщества, так как освещенные закономерности которые позволяют дать рекомендации по выращиванию сои и нута, сорта которых имеют минимальную способность к накоплению тяжелых металлов. Это социально необходимо и экономически выгодно, потому что позволит сохранить здоровье населения чем сэкономит средства государственного бюджета, предназначенные для больничных содержаний и выплат по инвалидности.

Ключевые слова: *почвы, черноземы, загрязнения, тяжелые металлы, свинец, методы детоксикации, бобовые.*

Шляхи оптимізації забруджених свинцем чорноземних ґрунтів у системі ґрунту – рослина

***Яна Олександрівна Білецька*[1],**
к. т. н., доцент, кафедра міжнародної електронної комерції та готельно-ресторанної справи,
[1]Харківський національний університет імені В.Н. Каразіна,
пл. Свободи, 4, м. Харків, 61022, Україна;
***Алла Наумівна Некос*[1],**
д. геогр. н., професор, кафедра екологічної безпеки та екологічної освіти;
***Анастасія Бехтер*[2],**
аспірант, секретар кафедри екологічної біотехнології,
[2]Лодзинський технологічний університет,
вул. Політехніка 3Б, 605, м. Лодзь, Польща, 90-535;
***Анна Сергіївна Крівцова*[1],**
к. екон. н., кафедра міжнародної електронної комерції та готельно-ресторанної справи;
***Ольга Іванівна Брайнінгер*[3],**
аспірант, [3]Державний біотехнологічний університет,
вул. Алчевських, 44, м. Харків, Україна, 61002

Екологічна безпека ґрунтів та вирощування екологічно безпечних харчових продуктів рослинного походження є однією з найактуальніших проблем сучасності. Забезпечення екологічної безпеки продовольчої сировини та харчових продуктів є одним із головних завдань, що визначають здоров'я популяції людини та збереження її генофонду. З їжею в організм людини з довкілля надходить до 70 % забруднюючих речовин різного походження. За даними Всесвітньої організації охорони здоров'я, свинець (Pb) є глобальним забруднювачем, який викликає велику кількість захворювань. Основна стратегія розробленого ООН проекту «Здоров'я нації в боротьбі з COVID-19» полягає у зменшенні інтоксикації важкими металами, що надходять в організм людини з їжею. У статті представлені результати дослідження шляхів оптимізації забруднених на свинець чорноземних ґрунтів у системі «ґрунт – рослина». Об'єкти дослідження були варіації сої та нуту різних сортів рослинності. Досліджено вміст білка, жирів, вуглеводів у зернах сої і нуту різних вегетаційних сортів за період 3 років, вирощених на чорноземах Київської області. Вивчено вміст свинцю у зернах сої та нуту із максимальним та мінімальним вмістом білка. Науково обґрунтовано процес акумуляції свинцю зернами сої та нуту в залежності від хімічного складу ґрунтів для вирощування. Встановлено, що за інтенсивністю детоксикації зерен сої та нуту різних вегетаційних сортів під час вирощування на чорноземах забруднених свинцем можна розподілити таким чином: $N_{180}P_{180}K_{180}$+ Pb + вапно + гній > $N_{360}P_{360}K_{360}$+ Pb > $N_{180}P_{180}K_{180}$+ Pb + гній > $N_{180}P_{180}K_{180}$+ Pb + вапно. Отримані результати досліджень є важливими для наукової спільноти, тому, що висвітлені закономірності дають змогу надати рекомендації до вирощування сортів сої та нуту, які мають найменшу здатність до накопичення тяжких металів. Що є соціально необхідним та економічно вигідним, тому що дозволить зберегти здоров'я населяння чим заощадить кошти державного бюджету, які призначені для лікарняних утримань та виплат по інвалідності.

***Ключові слова**: ґрунти, чорноземи, забруднення, важкі метали, свинець, методи детоксикації, бобові.*

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