СІЛЬСЬКЕ ГОСПОДАРСТВО

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AGRO-ENVIRONMENTAL RATIONALE OF SEWAGE SLUDGE PROCESSING AND APPLICATION

Conservation agriculture is becoming a priority for Ukraine as well as for many countries of the world. It is a known fact that high content of heavy metals in the soil impairs fertility and carries the risk of crops translocation. An agroecological effect of obtaining and applying organic-mineral fertilizers has been insufficiently studied so far.

The **purpose** of the work is to determine possibilities to produce new organic-mineral fertilizers based on sewage sludge with enhanced adsorbing properties, to establish their agroecological efficiency.

Methods. Field, laboratory-analytical, statistical-mathematical.

Results. From the agroecological point of view, the production process of organic-mineral fertilizers based on the sewage sludge of Kharkiv is justified. It allows us to expand functional capabilities of reagents, enhancing adsorbing properties of heavy metals. It is proved the advantage of organic-mineral fertilizers over the traditional ones on chernozem typical. After fertilization, the content of total carbon in the soil increased, the content of humic acids increased by 1,5 – 2,8 times, fulvic acids – by 1,1 – 1,7 times, the total sum of humic substances – by 1,3 – 2,1 times compared with no fertilizer option. It is established that application of organic-mineral fertilizers promotes blocking of heavy metals in soil and prevents translocation to plant. Maximum yields of corn were obtained after the local application of granular organic-mineral fertilizers – the yield increase was 41% compared to the control, after introduction of bulk fertilizers – 32% compared to the control. Profit was $ 23 -36 per hectare.

Conclusions. The process of organic-mineral fertilizers production on the basis of sewage sludge in Kharkiv is substantiated from the agro-ecological point of view. Agroecological and agrochemical efficacy of sewage sludge use as compared to organic and mineral fertilizers applied in equivalent doses separately was established on the typical heavy loam chernozem. After introduction of organic-mineral fertilizers based on sewage sludge a significant increase in the concentration of trace elements and heavy metals was found in the black soil but these indicators did not exceed the established maximum permissible concentrations. The implementation of the proposed technology will reduce bioavailability of heavy metals and their mobility in the soil which, in turn, impedes their accumulation in products. It is expected to increase soil fertility, crop yields and obtain environmentally friendly and safe products due to the stable composition of innovative fertilizers.

KEYWORDS: efficiency, heavy metals, organo-mineral fertilizers, plant, soil

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АГРОЕКОЛОГІЧНЕ ОБҐРУНТУВАННЯ ТЕХНОЛОГІЇ ПЕРЕРОБКИ ТА ЗАСТОСУВАННЯ ОСАДІВ СТІЧНИХ ВОД

Екологізація землеробства стає пріоритетним напрямком його розвитку в Україні та у багатьох країнах світу. Відомо, що надмірна кількість у ґрунті важких металів погіршує родючість та несе ризик транслокації у рослинницьку продукцію. Вкрай недостатньо досліджень, спрямованих на одержання та застосування органо-мінеральних добрив, які мають агроекологічний ефект.

Мета. Визначити можливості одержання нових органо-мінеральних добрив на основі осадів стічних вод з підвищеними адсорбуючими властивостями, встановити їхню агроекологічну ефективність та надати рекомендації щодо екологобезпечного застосування у сільському господарстві.

Методи. Польовий, лабораторно-аналітичний, статистично-математичний.

Результати. З агроекологічної точки обґрунтовано зору процес виробництва органо-мінеральних добрив на основі осадів стічних вод м. Харкова, який дає змогу розширити функціональні можливості реагентів з посиленням адсорбуючих властивостей до важких металів. На чорноземі типовому встановлено агроекологічну та агрохімічну ефективність органо-мінеральних добрив. Доведено перевагу органо-мінеральних добрив перед традиційними добривами. Після внесення добрив збільшився вміст загального вуглецю в ґрунті, вміст гумінових кислот збільшився у 1,5 - 2,8 рази, фульвокислот – у 1,1 – 1,7 рази, сума гумусових речовин – у 1,3 – 2,1 разі порівняно з варіантом без внесення добрив. Після внесення органо-мінеральних добрив розширюється співвідношення Сгк/Сфк і зростає ступінь гуміфікації. Встановлено, що внесення органо-мінеральних добрив, завдяки підвищеному вмісту в їхньому складі гумінових і фульвокислот, сприяє блокуванню важких металів у ґрунті та перешкоджає транслокації у рослинницьку продукцію. Максимальні врожаї кукурудзи одержано після локального внесення гранульованих органо-мінеральних добрив – приріст урожаю становив 41 % порівняно з контролем, після внесення сипучої форми добрив – 32 % порівняно з контролем Чистий прибуток становив від 534 до 848 грн. з 1 га. Розроблені рекомендації щодо виробництва органо-мінеральних добрив та їх застосування у сільському господарстві, важливо, у першу чергу, впровадити на комплексі біологічної очистки «Безлюдівський».

Висновки. Обґрунтовано з агроекологічної точки зору процес виробництва органо-мінеральних добрив на основі осадів стічних вод м. Харкова. На чорноземі типовому важкосуглинковому встановлено агроекологічну та агрохімічну ефективність застосування органо-мінеральних добрив порівняно з органічними і мінеральними добривами, які вносили в еквівалентних дозах окремо. Доведено перевагу органо-мінеральних добрив перед традиційними добривами. Встановлено, що внесення органо-мінеральних добрив, завдяки підвищеному вмісту у їх складі гумінових і фульвокислот і органічної речовини, сприяє блокуванню важких металів у ґрунті та перешкоджає їхньому накопиченню у рослинницької продукції. За рахунок стабілізованого складу інноваційного добрива очікується підвищення родючості ґрунту, урожайності культур та отримання екологічно чистої і безпечної продукції, тобто мають агроекологічний ефект.

КЛЮЧОВІ СЛОВА: ефективність, важкі метали, органо-мінеральні добрива, рослина, ґрунт

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АГРОЭКОЛОГИЧЕСКОЕ ОБОСНОВАНИЕ ТЕХНОЛОГИИ ПЕРЕРАБОТКИ И ПРИМЕНЕНИЯ ОСАДКОВ СТОЧНЫХ ВОД

Экологизация земледелия становится приоритетным направлением его развития в Украине и во многих странах мира. Известно, что избыточное количество в почве тяжелых металлов ухудшает плодородие и несет риск транслокации в растениеводческую продукцию. Крайне недостаточно исследований, направленных на получение и применение органо-минеральных удобрений, которые имеют агроэкологический эффект.

Цель. Определить возможности получения новых органо-минеральных удобрений на основе осадков сточных вод с повышенными адсорбирующими свойствами, установить их агроэкологическую эффективность и дать рекомендации по экологобезопасному применению в сельском хозяйстве.

Методы. Полевой, лабораторно-аналитический, статистическо-математический.

Результаты. С агроэкологической точки зрения обоснованно процесс производства органо-минеральных удобрений на основе осадков сточных вод г. Харькова, который позволяет расширить функциональные возможности реагентов с усилением адсорбирующих свойств к тяжелым металлам. На черноземе типичном установлено агроэкологическую и агрохимическую эффективность органо-минеральных удобрений. Доказано преимущество органо-минеральных удобрений перед традиционными удобрениями. После внесения удобрений увеличилось содержание общего углерода в почве, содержание гуминовых кислот увеличилось в 1,5 – 2,8 раза, фульвокислот – в 1,1 – 1,7 раза, сумма гуминовых веществ – в 1,3 – 2,1 сравнительно с вариантом без внесения удобрений. После внесения органо-минеральных удобрений расширяется соотношение $С_{гк}/С_{ФК}$ и возрастает степень гумификации. Установлено, что внесение органо-минеральных удобрений, благодаря повышенному содержанию в их составе гуминовых и фульвокислот, способствует блокированию тяжелых металлов в почве и препятствует транслокации в растениеводческую продукцию. Максимальные урожаи кукурузы получено после локального внесения гранулированных органо-минеральных удобрений - прирост урожая составил 41% по сравнению с контролем, а после внесения сыпучей формы удобрений – 32% по сравнению с контролем. Чистая прибыль составила от 534 до 848 грн. с 1 га. Разработаны рекомендации по производству органо-минеральных удобрений и их применение в сельском хозяйстве. Важно, в первую очередь, внедрить на комплексе биологической очистки «Безлюдовский».

Выводы. Обоснованно с агроэкологической точки зрения процесс производства органо-минеральных удобрений на основе осадков сточных вод г. Харьков. На черноземе типичном тяжелосуглинистом установлено агроэкологическую и агрохимической эффективность применения органо-минеральных удобрений по сравнению с органическими и минеральными удобрениями, которые вносили в эквивалентных дозах отдельно. Доказано преимущество органо-минеральных удобрений перед традиционными удобрениями. Установлено, что внесение органо-минеральных удобрений, благодаря повышенному содержанию в их составе гуминовых и фульвокислот и органического вещества, способствует блокированию тяжелых металлов в почве и препятствует их накоплению в растениеводческой продукции. За счет стабилизированного состава инновационного удобрения ожидается повышение плодородия почвы, урожайности культур и получения экологически чистой и безопасной продукции, то есть имеют агроэкологический эффект.

КЛЮЧЕВЫЕ СЛОВА: эффективность, тяжелые металлы, органо-минеральные удобрения, растение, почва

Introduction

Soil cover is one of the major environmental components that performs vital functions of the biosphere. Soils are the main means of agricultural production. They regulate composition of atmospheric air, the quality of surface and groundwater, being the habitat of most living organisms on the land surface, providing favorable environment for humans. It is known that the loss of soil fertility deprives plants of the ecological basis for their existence. Restoration of degraded soils is the preservation of the ecology of the territory, upset by man as a result of irrational economic activity [1, 2, 3]. Greening of agriculture is becoming a priority area of its development in Ukraine and in many countries of the world, connected with increasing anthropogenic impact on the environment and human health [4, 5]. One of the results of human activity is soil contamination with heavy metals (HM) [6, 7]. It has been determined that excessive amount of HM in the soil worsens physical, physical-chemical, microbiological and agrochemical properties, increasing the content of HM in plant production [8, 9, 10]. Due to this situation, rational use of various natural raw materials (sapropel, peat) and waste of organic origin (first of all, avian manure, cattle manure, sewage sludge, etc.) and production on their basis of composts and complex organic-mineral fertilizers (OMFs) with high adsorption properties is necessary [11, 12, 13, 14, 4]. A lot of attention has been paid in current literature to sewage sludge due to its increasing amount and problem with its disposal. Many researchers reported positive effects of using sewage sludge in agriculture [15, 16]. The importance of sewage sludge as a valuable source of matter and energy has been appreciated, as well as a potential risk related to the application of those strategies [17]. Research on the scientific and practical substantiation of sewage sludge (SS) processing into complex organic-mineral fertilizers (OMFs) with increased adsorption properties and their application in agricultural production, given the current state of soils in Kharkiv region, is relevant. The use of these fertilizers will help increase the crops productivity, improve their quality by reducing incoming heavy metals into plant products, preserving soil fertility, decreasing environmental pollution by toxicants. The purpose of the work is to determine possibilities to obtain new organic-mineral fertilizers based on sewage sludge with enhanced adsorbing properties, to establish their agroecological efficiency and to make recommendations for environmentally safe application in agriculture. The research was conducted in 2018 (technological and part of laboratory experiments) and in 2019 (field experiment) at the National Scientific Center "O.N. Sokolovsky Institute of Soil Science and Agrochemistry Research" in the laboratory of organic fertilizers and humus (Certificate of compliance of the measurement system with the requirements of DSTU ISO 10012: 2005 No. 01-0104 / 2017).

Materials and methods

Model-technological experiments were carried out on the working hypothesis of obtaining fertilizers of prolonged action by physical-chemical and chemical interaction of components of different origin to obtain OMFs on the basis of SS, to reduce nutrient losses, increase the content of humic substances (humic and fulvic acids) to enhance the adsorption properties of new fertilizers [18]. The algorithm for calculation of OMFs production by individual technological stages is given in the schemes and Eqs. 1 to 7.

Step 1. Quality control → Organic raw materials (sewage sludge, peat) → Conditioning and synchronization of the mixture with mineral and organic components → Calculation of the number of source components:

<u>Mineral fertilizers</u>

$$N = \frac{N_X}{C_N} \cdot 100 - N_C, \qquad (1)$$

$$P = \frac{P_X}{C_P} \cdot 100 - P_C, \qquad (2)$$

$$K = \frac{K_X}{C_K} \cdot 100 - K_C, \qquad (3)$$

<u>Organic component</u>

$$O = 1000 - N - P - K - Nc - Pc - Kc, \qquad (4)$$

Step 2. Managed aero-composting of organic-mineral mixture → Enrichment by a starting complex of nutrients → Calculation of quantity of starting components for enrichment of nutrients starting complex

Step 3. Quality control → Calculation of total nutrient content in the final fertilizer:

$$Nz = \frac{O \cdot O_N}{100} + \frac{N \cdot C_N}{100} + \frac{N_C \cdot C_N}{100}, \qquad (5)$$

$$Pz = \frac{O \cdot O_P}{100} + \frac{P \cdot C_p}{100} + \frac{P_c \pm C_N}{100}, \qquad (6)$$

$$Kz = \frac{O \cdot O_K}{100} + \frac{K \cdot C_K}{100} + \frac{K_C \cdot C_K}{100}, \qquad (7)$$

where: N is the physical mass of nitrogen fertilizers for the main complex, kg;

P – physical mass of phosphorus fertilizers for the main complex, kg;

K – physical mass of potassium fertilizers for the main complex, kg;

O – physical mass of the organic component (kg);

N_X – the planned content of nitrogen active substance of mineral fertilizers in 1 ton of final fertilizer, kg;

P_X – the planned content of active phosphorus substance of mineral fertilizers in 1 t of final fertilizer, kg;

K_X – the planned content of the active substance of potassium mineral fertilizers in1 ton of final fertilizer, kg;

C_N – content of nitrogen active substance in nitrogen fertilizers,%;

C_P – content of active substance of phosphorus in phosphorus fertilizers,%;

C_K – content of potassium active substance in potassium fertilizers,%;

N_C – physical mass of nitrogen fertilizers for the starting complex, kg;

P_C – physical mass of phosphorus fertilizers for the starting complex, kg;

K_C – physical mass of potash fertilizers for the starting complex, kg;

N_Z – total content of nitrogen active substance in 1 ton of final fertilizer, kg;

P_Z – total content of active substance of phosphorus in 1 ton of final fertilizer, kg;

K_Z – total content of the active substance of nitrogen in 1 t of the final fertilizer, kg;

O_N – content of active ingredient nitrogen of organic component in 1 ton of final fertilizer, kg;

O_P – content of active ingredient of organic phosphorus component in 1 t of final fertilizer, kg;

O_K – content of active ingredient of organic potassium component in 1 ton of final fertilizer, kg;

C – is the proportion of starting active substance in the total mass of active substance of the corresponding element (%);

100 – conversion rate from percent to kilograms;

1000 – OMFs mass, which is being calculated, kg.

SS from the biological treatment complex "Bezlyudivsky" in Kharkiv, lowland peat, liquid mineral fertilizers (technical ammonia water, liquid complex fertilizers) were used in the research. Doses of SS and fertilizers application were calculated according to accepted methods, taking into account the reduction of pollution by heavy metals, without disturbing the balanced nutrition of plants.

Agro-ecological efficiency of OMFs activity was studied on the basis of sewage sludge using different methods of application of corn on silage, production quality, elements of soil fertility and new fertilizers' impact on the processes of heavy metals transformation in the system of fertilizer – soil – plant at Slobozhans'kyi experimental field» O. N. Sokolovsky Institute of Science and Technology in field experience according to the following scheme:

Scheme of the experiment

1. Without fertilizers (control)
2. Organic Component (SS) – Scattered (Comparison Option) at N_{60} dose
3. Organic component (SS) – locally (comparison option) at a dose of N_{60}
4. OMFs – dose rate calculation based on $N_{60}P_{60}K_{60}$
5. OMFs – locally at a dose of $N_{60}P_{60}K_{60}$
6. NPK Mineral Fertilizer – Scattered (Comparison Option) at a Dose of $N_{60}P_{60}K_{60}$
7. NPK mineral fertilizer – locally (comparison option) at a dose of $N_{60}P_{60}K_{60}$

The experiment repeated – 4 times. The size of the accounting area – 10 m^2.

Soil – chernozem typical heavy-loam with total nitrogen content – 0.23 – 0.27%, total phosphorus – 0.20 – 0.24%, mobile forms of phosphorus – 58.6, potassium – 88.9 mg/kg soil, nitrogen in mineral form – 22.0 mg/kg of soil, pH – 6.8.

The dose of sewage sludge according to the content of heavy metals was calculated by Eq. 8 [19].

$$N_{mm} = ((\mathrm{MPC} - \mathrm{F}) \times 3 \times 10^3)/\mathrm{C}, \quad (8)$$

where: N_{mm} is the SS dose by HM content, t/ha; MPC – maximum permissible concentration of metal in soil, mg/kg; F – background content of metal in soil, mg/kg; 3×10^3 – mass of arable soil, t/ha; C – metal content in SS, mg / kg.

Analyses of soil, plants, sewage sludge, lowland peat and organic-mineral fertilizers on their basis were performed according to the current regulatory documents, namely: the mass fraction of moisture was determined by gravimetric method according to DSTU ISO 11465 [20]; determination of the reaction of the medium (pH) according to DSTU ISO 10390 [21]; mass fraction of total carbon was determined oxidimetrically according to DSTU 4289 Soil quality [22]; group and fractional composition of humus according to the method of I.V. Tyurin in the modification of V.V. Ponomareva and T.A. Plotnikova according to DSTU 7828 [23]; mass fractions of moving compounds of trace elements and heavy metals– by atomic absorption method on a Saturn-4 spectrophotometer according to DSTU 4770.1– DSTU 4770.9 [24-27]; the total mass fraction of nitrogen and mass fraction of ammonium nitrogen according to DSTU 7911 [23]; phosphate mass fraction according to DSTU ISO 5316 (DSTU, 2003]; mass fraction of total potassium according to DSTU 7949 [28]; mass particles of trace elements and heavy metals by atomic emission spectrometry according to DSTU ISO 11885 [22]; mass particles of common forms of nitrogen, phosphorus, potassium according to MVB 31-497058-019. The results obtained during the research were processed by methods of mathematical statistics using standard programs Exel and Statistica 6.0.

Results and discussion

Scientific research has shown asignificant agro-potential of sewage sludge to be used in agricultural production. Positive SS effect on agrochemical, biological, water-physical, physical-chemical parameters in different soils has been established [29]. The high content of organic matter in sediment contributes to the increase in humus reserves while improving its quality in the soil, as well as carbon sequestration, which will favourably influence the environment. The agrochemical composition of SS from the biological treatment complex "Bezlyudivsky" in Kharkiv is shown in Table 1.

Table 1

Agrochemical composition of SS from the complex of biological treatment "Bezlyudivsky" in Kharkiv

№	Index	Actual content,% on dry matter			
		1	2	3	Average
1	Dry matter	45,56	42,21	44,39	44,05
2	Organic matter	57,25	54,36	52,11	54,57
3	Total carbon, Ctotal	21,44	22,01	22,54	21,99
4	Total nitrogen, N	2,95	2,84	3,24	3,01
5	Total phosphorus, P_20_5	3,53	4,97	4,75	4,42
6	Total potassium, K_2O	0,20	0,27	0,22	0,23
7	pH	6,4	6,7	6,5	6,5

It has been found that the content of organic matter in the SS is 54% on average, the total basic nutrients of plants is 7.66%. It should be noted that this waste is characterized by a low content of potassium, its content is only 3% of the amount of nutrients. In general, the investigated sewage sludge meets the requirements of the current DSTU 7369 [19] according to agrochemical parameters. It is known that the main factor limiting the use of sludge for fertilizer crops is the content of heavy metals [24 – 27]. According to the results of analytical work, it has been found that the content of heavy metals and trace elements does not exceed the permissible concentrations in the studied sediments from the biological treatment complex "Bezlyudivsky" in Kharkiv (Table 2).

Model-technological work to obtain OMFs on the basis of SS was carried out in laboratory conditions. To obtain organic fertilizers, the starting components were mixed in appropriate proportions. According to the calculation, the initial composition was as follows: sewage sludge 70%, lowland peat 20%, ammonia water 5%, and liquid mineral fertilizers 5%. Agroecological and agrochemical evaluation of OMFs after composting are shown in Table 3.

Table 2

Agroecological evaluation of SS on the content of trace elements and heavy metals in Kharkiv and compliance with normative requirements DSTU 7369 [19]

S.№	Index	Content (mg/kg)				Valid values for SS DSTU 7369		
		1	2	3	Average	Group 11	Group 22	Group 33
1	Co	7,63	8,02	7,97	7,87	5-20	20-50	50-100
2	Cu	712,33	720,81	734,93	722,69	100-300	300-700	700-1500
3	Mn	611,05	621,54	629,75	620,78	250-750	750-1500	1500-2000
4	Ni	59,45	62,78	61,98	61,38	50-75	75-150	150-200
5	Zn	1096,77	1091,05	1100,92	1096,25	300-1000	1000-2000	2000-2500
6	Pb	5,95	6,54	6,09	6,19	100-200	400-600	600-750
7	Cd	14,07	15	14,72	14,59	3-5	5-15	15-30
8	Cr	60,12	58,68	59,66	59,48	100-400	400-600	600-750

1. Use (or production of compost) in doses adequate to standard fertilizers
2. Use at a dose of 3-4 t / ha annually or no more than 10 t / ha every three years
3. Use at a dose of 5-6 t / ha on dry matter once every 5 years with mandatory control of the background content of the elements in the soil.

Table 3

Agroecological and agrochemical evaluation of OMFs on the basis of SS

S.№	Index	Actual content on dry matter
1.	Dry matter (%)	51,56
2.	Organic matter (%)	79,27
3.	Humic acids (%)	5,88
4.	Fulvic acids (%)	2,74
5.	Humus substances (%)	8,62
6.	Total nitrogen, N (%)	4,84
7.	Total phosphorus, P_2O_5 (%)	4,75
8.	Total potassium, K_2O (%)	4,57
9.	Cu (mg/kg)	826,55
10.	Fe (mg/kg)	18004,0
11.	Mn (mg/kg)	731,95
12.	Zn (mg/kg)	1112,15
13.	Ni (mg/kg)	53,78
14.	Pb (mg/kg)	7,05
15.	Cd (mg/kg)	11,15
16.	Cr (mg/kg)	59,50
17.	pH	6,9

It has been established that after aerobic composting and activation of organic peat with nitrogen-containing compounds in the OMFs the content of humic substances (humic and fulvic acids) increased significantly. This fact indicates an increase in the adsorption properties of the new fertilizer to block the flow of heavy metals to crop production and complex formation in the soil. In the field experiment on heavy-loam typical chernozem we have established agrochemical and agro-ecological effectiveness of OMFs on the basis of SS in Kharkiv on soil fertility elements, corn yield on silage and output quality. The advantages of OMFs were compared with traditional mineral fertilizers and SS, which were introduced separately. Maximum yields of corn silage were obtained after the local application of granular OMFs - the yield increase was 11,7 t / ha or 41% compared to the control, after introduction of bulk fertilizers – 9,0 t / ha or 32% compared to the control (Table 4).

After introduction of the initial SS, the yield of corn silage in the spread-out way was 30, 4 t / ha or 7% compared to the control, in local application – 32,5 t / ha or 16%. After

Table 4

Effectiveness of OMFs based on SS on the yield of corn silage

S.№	Variant	Yield (t/ha)			Average yield (t/ha)	Increase in control	
		1	2	3		t/ha	%
1	Without fertilizers (control)	25,8	29,6	29,5	28,3	-	-
2	SS	27,7	31,8	31,7	30,4	2,1	7
		28,8	34,3	34,3	32,5	4,2	15
3	OMFs loose	30,3	38,4	38,1	35,6	7,3	26
		31,1	39,2	41,5	37,3	9	32
4	OMFs granular	31,2	34,6	41,8	35,8	7,5	26
		37,7	37,6	44,8	40	11,7	41
5	NPK	27,9	32,9	36,6	32,5	4,2	15
		32,8	35	38,6	35,5	7,2	25

Note: Above the line – spread of fertilizer; under the line - fertilizing locally

fertilizer application, the yield of corn silage was at the level of 4,2 to 7,2 t / ha or 15 - 25%. In a field experiment, it has been found that the introduction of OMFs on the basis of SS actively affects the transformation of humus qualitative composition in typical chernozem (Table 5).

Application of organic-mineral fertilizers based on sewage sludge has been found to significantly increase the content of organic matter and improve its qualitative composition in the upper layer of typical chernozem. After fertilization, the content of total carbon in the soil increased, the content of humic acids increased by 1,5 – 2,8 times, fulvic acids - by 1,1 – 1,7 times, the total sum of humic substances - by 1,3 – 2,1 times compared with no fertilizer option. After OMFs introduction, the ratio of *Thc/Tfc* expands and the degree of humification increases.

These processes are primarily due to the organic component contained in the fertilizers.They indicate that the fertilizers have good adsorbing properties with respect to the pollutants and, therefore, are of agro-ecological value. The use of sewage sludge and fertilizers on their basis is limited by the content of heavy metal salts in their composition. However, it is known that the main thing is not the presence of the element, but its concentration. Copper, cobalt, zinc, manganese are classified as heavy metals, but their role is very important in shaping crop yields and product quality. Soil is not always a complete source of trace elements for plants. Thus, the content of these elements in fertilizers is considered a positive factor. However, the use of sewage sludge and fertilizers based on it in crop production involves a monitoring system of of heavy metals accumulation in soil and products. In the field experiment we determined the OMFs effect based on SS on the content of mobile forms of trace elements and heavy metals in the typical chernozem (content after application Locally; denominator – content after Scattering) (Table 6).

In plants, the accumulation of heavy metals depends on many factors: biological features of species (their ability to transform metal compounds into a physiologically inactive state), the content of organic matter in the soil and its quality, the reaction of soil solution, soil buffer, etc.

The effects of long-term application of sewage sludge on metal distribution in the soil profile, the response of crop yields, and the bioavailability of metals were reviewed, using results from field trials. It has been established that introduction of OMFs based on SS did not inhibit the growth and development of maize plants. The content of trace elements and heavy metals in the corn silage did not exceed maximum permissible levels in coarse and juicy feeds for farm animals (Table 7).

Agrochemical measures must be economically viable and energy-justified in agriculture. After application of bulk organic fertilizers in corn on silage, a conditionally net profit was obtained from UAH 694 to 822 per 1 ha, granular fertilizers − at the level of UAH 534 − 848 per 1 ha. At local application of organic-mineral fertilizers net income was 1.2 −1.6 times higher than the application of fertilizers in spread. The review (Huang and Yuan, 2016)

Table 5

Changes in quality indicators of humus of black soil typical under the influence of OMFs based on SS

S.№	Variant	C_{total} (%)	Humic acids, %	Fulvic acids, %	Humines, %	Total humic and fulvic acids, %	Thc/Tfc
1	Without fertilizers (control)	1,75	0,61/1,09	0,81/1,70	0,33	1,42/2,79	0,7
2	SS	2,22	1,03/1,85	0,89/1,87	0,3	1,92/3,72	1,2
3	OMFs loose	3,48	1,71/3,08	1,36/2,86	0,41	3,07/5,94	1,3
4	OMFs granular	2,6	0,92/1,66	0,92/1,93	0,76	1,84/3,59	1
5	NPK	1,52	0,31/0,56	0,78/1,64	0,43	1,09/2,20	0,4

Note: Before the line - carbon content, after the line - content of the substance

Table 6

The content of mobile forms of microelements and heavy metals in the chernozem typical after local application of OMFs on the basis of SS

S.№	Variant		Content , mg/kg in soil							
			Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
1	Without fertilizers (control)		0,06	0,47	0,69	0,35	45,72	0,66	0,44	0,98
2	SS	Locally	0,17	0,58	0,79	0,44	47,34	0,88	0,54	1,65
		Scattering	0,15	0,53	0,77	0,41	47,36	0,81	0,58	1,69
3	OMFs loose	Locally	0,1	0,59	0,74	0,38	54,73	0,75	0,41	1,82
		Scattering	0,09	0,54	0,77	0,36	53,82	0,73	0,42	1,9
4	SS granular	Locally	0,08	0,51	0,72	0,37	58,36	0,77	0,4	1,72
		Scattering	0,07	0,5	0,8	0,36	57,39	0,8	0,45	1,77
5	NPK	Locally	0,05	0,32	0,5	0,29	40,03	0,55	0,3	0,91
		Scattering	0,04	0,41	0,55	0,38	41,42	0,5	0,38	0,92
6	HIP_{05}	Locally	0,03	0,1	0,02	0,01	1,1	0,12	0,05	0,21
		Scattering	0,02	0,09	0,05	0,02	1,6	0,13	0,03	0,19
7	MPC (mg/kg) in soil		-	5	6	3	-	4	6	37

Table 7

Effect of OMFs based on SS on the content of microelements and heavy metals in corn silage (content after application Locally; denominator - content after Scattering)

S.№	Variant		Content, mg/kg of dry substance, average from 3 repetitions						
			Cu	Fe	Zn	Ni	Co	Cd	Pb
1	Without fertilizers (control)		5,8	34,9	5,5	0,7	0,45	0,09	0,56
2	SS	Locally	10,64	50,54	20,64	2,95	0,95	0,63	3,21
		Scattering	10,59	50,47	20,44	2,84	0,78	0,59	3,33
3	OMFs loose	Locally	9,76	49,75	19,98	1,22	0,62	0,28	2,25
		Scattering	9,21	49,43	19,77	1,01	0,66	0,29	2,58
4	OMFs granular	Locally	8,57	48,91	18,32	1,78	0,68	0,29	1,84
		Scattering	8,48	48,62	18,35	1,34	0,54	0,30	2,06
5	NPK	Locally	12,03	34,83	9,03	0,95	0,55	0,30	3,15
		Scattering	12,39	34,65	9,65	0,82	0,52	0,34	3,01
6	MPC in maize, mg/kg of dry substance		30,0	100,0	50,0	3,0	1,0	0,3	5,0

discussed the migration and transformation behaviors of heavy metals from the following aspects: the effect of reaction temperature, the effect of additives (catalysts and other biomass), the effect of the solvent type and reac tion time. It has been found that after introduction of OMFs based on SS in chernozem typical the concentration of trace elements and heavy metals increased, but these indicators did not exceed the established MPC.

Conclusion

The process of OMFs production on the basis of SS in Kharkiv is substantiated from the agro-ecological point of view. The study of sewage sludge from sludge sites of wastewater treatment plants has showed that a sufficiently high content of organic matter (more than 70%) and basic nutrients (common forms of nitrogen, phosphorus) determines the prospects of using the investigated SS as fertilizers. Low humidity of the samples (48%) is a very important factor in saving transportation costs and greatly simplifies agricultural practices for the introduction of SS into the soil. Processing of organic raw materials based on a conceptual model of humus compounds formation in the process of conditioning has been developed in contrast to traditional approaches. It allows us to expand the functionality of the reagents by enhancing the adsorbing properties of fertilizers in relation to pollutants (heavy metals). Agroecological and agrochemical efficacy of SS use as compared to organic and mineral fertilizers applied in equivalent doses separately was established on the typical heavy loam chernozem. SS advantage over traditional fertilizers has been proved. Economic efficiency of organic-mineral fertilizers was higher in case of their local application. The granular SS form had advantage over bulk fertilizers of similar composition as to their effectiveness and impact on crop yields. Introduction of SS, due to the increased content of humic and fulvic acids and organic matter, helps block heavy metals in the soil and prevents their accumulation in plant products.After introduction of organic-mineral fertilizers based on sewage sludge a significant increase in the concentration of trace elements and heavy metals was found in the black soil but these indicators did not exceed the established MPCs. In our opinion, the increased content of quality organic matter in the composition of fertilizers has played a positive role in these processes, namely, humic substances (humic and fulvic acids), which improve the adsorbing properties of fertilizers. The implementation of the proposed technology will reduce bioavailability of heavy metals and their mobility in the soil which, in turn, impedes their accumulation in products. It is expected to increase soil fertility, crop yields and obtain environmentally friendly and safe products due to the stable composition of innovative fertilizers.

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Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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