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Changes in the Key Agrochemical Properties of Soddy-Podzolic Soil After Fertilisation of Jerusalem Artichoke with Sewage Sludge

Abstract. Studies have shown that the introduction of sewage sludge and composts based on it under Jerusalem artichoke significantly affects the change in agrochemical parameters of soddy-medium-podzolic soil, contributing to an increase in the content of alkaline-hydrolysed nitrogen compounds by 2.2-13.4 mg/kg of soil compared to the control and determining the content at the level of 51.2-56.5 mg/kg of soil in the upper (0-20 cm) and 27.9-31.6 mg/kg of soil – in the lower (20-40 cm) soil layer. The content of ammonium nitrogen compounds in the variants with fertiliser application fluctuated in a small range of values (16-21 mg/kg of soil) and increased under the influence of increasing fertilizer doses. Along with the change in the content of nitrate nitrogen, this contributed to an increase in the content of mineral nitrogen compounds in the soil in the range of 18.5-23.4 mg/kg of soil in the arable (0-20 cm) and 19.8-21.9 mg/kg of soil – in the subsoil (20-40 cm) layers, which is 1.7-2.2 mg/kg of soil higher than the control variant. The highest values of mineral nitrogen compounds were recorded in the variant where the highest dose of sewage sludge – 40 t/ha and mineral fertilisers were applied ($N_{10}P_{14}K_{58}$). Despite a wide range of nitrogen content values for alkaline hydrolysed compounds and mineral nitrogenous compounds, their ratio remained stable and amounted to 2.3-2.6 in the upper and 1.3-1.5 in the lower (20-40 cm) soil layer, and also decreased with increasing fertiliser application dose. That is, this parameter varied insignificantly depending on the dose of fertiliser application. The content of mobile phosphorus compounds in the variants with the use of fertilisers fluctuated in the range of values (77.5-98.5 mg/kg of soil) and increased under the influence of sewage

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sludge and composts based on it, which exceeded the control values by 14.6-35.6 mg/kg of soil. The highest rates of mobile phosphorus compounds were recorded in the variant where sewage sludge was applied – 40 t/ha and N10P14K58.10P14K58. The introduction of sewage sludge at a dose of 20-40 t/ha contributed to an increase in the content of exchangeable potassium compounds at the level of 89.3-97.2 mg/kg of soil in the upper (0-20 cm) and 83.1-93.4 mg/kg of soil – in the lower (20-40 cm) layer, which is more than 42.1 mg/kg of soil exceeded the control variant. To a lesser extent, the content of exchangeable potassium compounds increased with the introduction of composts based on sewage sludge and straw. The correlation and regression analysis indicates that the coefficient of phosphorus concentration in the soil depends to the greatest extent on the content of its mobile compounds with the coefficient of determination R2 = 0.70. The potassium concentration coefficient closely (R2 = 0.91) correlates with the content of its metabolic compounds in the soil

Keywords: soil, fraction, nitrogen, phosphorus, potassium, concentration coefficient, correlation and regression analysis

RELEVANCE

Ukraine is demonstrating growing interest in growing crops for energy purposes, for which areas of mainly low-productive degraded soils are allocated outside crop rotations. Being characterised by high biological productivity, such crops respond well to the application of fertilisers, in particular organic fertilisers, which not only improve the nutrient regime of the soil but also contribute to the realisation of its bioproductive and ecological functions. Due to the acute shortage of conventional types of organic fertilisers in agriculture in Ukraine, there is a need to find alternative sources of organic raw materials for application as fertilisers for bioenergy crops.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Sewage sludge (SS), which accumulates in excess volumes in Ukraine, can be used as fertiliser, provided that the requirements of environmental safety of such use are met and the content of heavy metals and other pollutants in it is acceptable (Hrytsuliak & Lopushniak, 2017, Hetmanenko, 2016, Kholodna, 2016, Berdnikov *et al.*, 2019, Yang *et al*, 2015, Rossini *et al*, 2019). The use of SS for bioenergy crops has significant prospects and partially solves the problem of utilisation of its large accumulated reserves in the municipal sector, and also provides plants with the necessary macro- and microelements. Sewage sludge contains a significant amount of essential nutrients for the proper growth and development of plants (Onyshchuk *et al.*, 2004, Chebotko, 2000, Hetmanenko & Skrylnyk, 2017, Lamastra, 2018). Therefore, this raw material resource should be considered an important element of energy- and resource-saving environmentally friendly biological crop cultivation technologies, in particular, energy technologies. Another promising area is the preparation of composts based on SS and other organic materials, in particular, cereal straw, etc. Application of such composts enhances the humus-forming capacity of the soil due to the supply of additional organic substances and intensification of the development of beneficial microflora, which contributes to the improvement of the mineral nutrition regime of plants, which provides increased bioproductivity of agro phytocoenoses (Hospodarenko, 2015, Dubovyi *et al.*, 2018, Onyshchuk, 2004, Ruf, 2019).

A promising method of SS utilisation is using them as fertilisers, provided that they meet the regulatory requirements for the content of pollutants, which contributes to solving several problems at once: ensuring the supply of organic matter and nutrients to the soil and reducing the intensity of its accumulation in sludge maps of municipal enterprises (Madzhd *et al.*, 2017, Yakymenko, 2001, Krutyakova, 2020).

The purpose of this study is to determine the changes in agrochemical parameters of sod-podzolic soil with the application of different doses of fertilisers based on SS for Jerusalem artichoke.

MATERIALS AND METHODS

Studies on the efficiency of sewage sludge application into one of the most promising bioenergy crops – Jerusalem artichoke – were conducted in a field experiment on sod-podzolic soils of Ivano-Frankivsk oblast (Lopushniak & Hrytsuliak, 2017).

The soil of the experimental plot is soddy-medium podzolic. The redistribution of the colloidal fraction of the eluvial and illuvial horizons is distinctly pronounced. Humus-eluvial (NE) horizon up to 18-25 cm, darkish grey, lumpy-dusty, loose, with SiO_2 particles. Eluvial horizon (E) up to 45 cm yellowish-whitish. The illuvial (I) horizon is characterised by a pronounced alternation of whitish sand layers with dense red-brown loam layers up to 8 cm. The studied soil was characterised by the following agrochemical indicators: humus content in the arable (0-20 cm) layer – 2.0%, salt pH – 4.8, hydrolytic acidity – 3.1 mmol/100 g of soil. The content of alkaline hydrolysed nitrogen compounds was 47 mg/kg of soil, mobile phosphorus compounds – 64, and exchangeable potassium – 42 mg/kg of soil (Lopushniak & Hrytsuliak, 2017).

The scheme of the experiment consisted of the following options: 1 – control (without fertilisers); 2 – $N_{60}P_{60}K_{60}$; 3 – $N_{90}P_{90}K_{90}$; 4 – SS 20 t/ha + $N_{50}P_{52}K_{74}$; 5 – SS 30 t / ha + $N_{30}P_{33}K_{66}$; 6 – SS 40 t/ha + $N_{10}P_{14}K_{58}$ 7 – compost (SS + straw in the ratio (3:1) 20 t/ha + $N_{50}P_{16}K_{67}$; 8 – compost (SS + straw in the ratio (3: 1)) 30 t/ha + $N_{30}K_{55}$. In variants of experiments 3-8, SS and compost were applied with a compensatory dose of mineral fertilisers based on the total number of nutrients applied $N_{90}P_{90}K_{90}$.

The study was carried out using sludge with the following characteristics: humidity – 76%, pH – 8.1, the content of ash elements, nitrogen, phosphorus and potassium was 5.0%, 4.0%, 3.8% and 1.6% (in terms of absolutely dry matter), respectively. Composts with SS and straw of grain crops in the ratio of 3:1 had the following chemical composition: organic matter content – 78%, pH_{HCl} – 7.2, the nitrogen of alkaline-hydrolysed compounds – 200.3 mg/kg of compost, phosphorus of mobile compounds – 371.2, potassium of exchange compounds – 115.4 mg/kg of compost. The chemical composition of non-traditional types of organic fertilizers was determined in the laboratory of analytical support of agrochemical research of the Ivano-Frankivsk branch of the State Institution Institute of Soil Protection of Ukraine "Derzhgruntokhora" according to generally accepted methods (Yakist gruntu[1], 2008, Yakist gruntu[2], 2008, Yakist gruntu, 2006).

The total area of the experimental plot is 63 m^2, and the accounting area is 35.0 m^2.

To evaluate the nitrogen fund of the soil after the application of SS, the content of various nitrogen compounds in the soil was measured. To determine the characteristics of the transformation of phosphorus and potassium compounds in the soil, the concentration coefficients of their compounds were calculated by the ratio of the content of each element in the experimental variants to its content in the background area (variant 1). The value of the concentration coefficients indicates the intensity of leaching processes in the soil (Madzhd *et al.*, 2016).

During the period of experimental research between 2016-2020, the content of total nitrogen in the studied soil was determined in the modification of the National Scientific Centre A. N. Sokolovsky Institute of Soil Science and Agrochemistry; DSTU 4729: 2007. Determination of nitrate and ammonium nitrogen in the modification of the NSC A. N. Sokolovsky Institute of Soil Science and Agrochemistry (Yakist gruntu[1], 2008, Yakist gruntu[2], 2008, Kholodna, 2016). Determination of mobile compounds of phosphorus and potassium by the Kirsanov method in the modification of the NSC A. N. Sokolovsky Institute of Soil Science and Agrochemistry; DSTU 4405:2005 (Yakist gruntu, 2006).

RESULTS

Studies have shown that the use of fertilisers significantly influenced the formation of the nitrogen fund of soddy-medium-podzolic soil (Table 1).

Table 1. The content of nitrogen compounds of different fractions in the layer of 0-40 cm of sod-podzolic soil for the application of sewage sludge and compost under Jerusalem artichoke, the average for 2016-2019

Variant	Soil layer, cm	Content of various nitrogen fractions in the soil			
		Ammonium	Nitrate	Alkaline	hydrolysed
		N_{NH4}^{+}	N_{NO3}^{-}	$N_{NH4}^{+} + N_{NO3}^{-}$	
		mg/kg of soil			
1. Without fertilisers (control)	0 - 20	15	1.68	16.78	43.12
	20 - 40	16	1.60	17.60	25.78
2. $N_{60}P_{60}K_{60}$	0 - 20	16	2.51	18.51	48.18
	20 - 40	18	1.84	19.84	27.83
3. $N_{90}P_{90}K_{90}$	0 - 20	18	2.75	20.75	49.34
	20 - 40	18	2.31	20.31	28.41
4. SS - 20 t/ha + $N_{50}P_{52}K_{74}$	0 - 20	19	2.54	21.54	51.20
	20 - 40	19	2.12	20.12	27.91
5. SS - 30 t/ha + $N_{30}P_{33}K_{66}$	0 - 20	20	2.29	22.29	52.41
	20 - 40	19	2.72	21.72	29.04
6. SS - 40 t/ha + $N_{10}P_{14}K_{58}$	0 - 20	21	2.41	23.41	56.49
	20 - 40	19	2.96	21.96	31.62
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{50}P_{16}K_{67}$	0 - 20	19	1.94	20.94	52.04
	20 - 40	19	1.62	20.62	28.56
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{30}K_{55}$	0 - 20	19	2.03	22.07	52.91
	20 - 40	19	2.56	21.56	30.12
LSD 0.5, mg/kg of soil	0 - 20	1.02	0.1	1.3	4.6
	20 - 40	1.01	0.1	1.1	2.2

In particular, the use of mineral fertilisers at a dose of $N_{60}R_{60}K_{60}$ contributed to an increase in the nitrogen content of alkaline hydrolysed compounds by 5 mg/kg of soil in the upper (0-20 cm) and 2 mg/kg in the lower (20-40 cm) layer, which amounted to 48.2 and 27.8 mg/kg of soil, respectively (Lopushniak & Hrytsuliak, 2017, Hrytsuliak & Lopushniak, 2017). An increase in the dose of nitrogen application with mineral fertilisers contributed to an increase in the nitrogen content of alkaline hydrolysed compounds in the soil. The application of OSV at a dose of 20-40 t/ha with the corresponding balance dose of mineral fertilisers caused an increase in alkaline hydrolysed nitrogen compounds by 8.1-13.3 mg/kg in the upper (0-20 cm) soil layer and by 28-31 mg/kg in the lower (20-40 cm). Slightly lower rates of growth of alkaline hydrolysed nitrogen compounds were achieved by the introduction of composts based on sewage sludge and straw, the content of alkaline-hydrolyzed nitrogen compounds was 52.0-52.9 in the upper layer of soil and 28.6-30.1 mg/kg of soil in the lower layer, which significantly exceeded the control variant.

The content of ammonium nitrogen compounds in the variants with fertiliser application fluctuated in a small range of values (16-21 mg/kg of soil) and increased under the influence of increasing fertilizer doses. Along with the change in the nitrogen content of nitrate compounds, this contributed to the formation of mineral nitrogen compounds in the soil in the range of 18.5-23.4 mg/kg of soil in the arable (0-20 cm) layer and 19.8-21.9 mg/kg of soil – in the subsoil (20-40 cm) layer. The highest rates of mineral nitrogen compound content were recorded in variant 6, where the highest dose of sewage sludge – 40 t/ha and the corresponding amount of mineral fertilisers were applied ($N_{10}P_{14}K_{58}$). The introduction of SS-based compost (variants 7 and 8) provided the content of mineral nitrogen compounds in the range of 21.5-22.1 mg/kg of soil.

Despite the wide range of values of the nitrogen content of alkaline hydrolysed compounds and mineral compounds, their ratio was 2.3-2.6 in the upper layer and 1.3-1.5 in the lower layer (20-40 cm) and reduced with increasing doses of fertilisers. Thus, the ratio of the content of alkaline hydrolysed nitrogen compounds to the nitrogen content of mineral compounds can be considered a relatively stable indicator of soil characteristics, which does not change significantly depending on the use of fertilisers.

The use of SS and composts based on it led to a significant increase in the content of mobile phosphorus compounds and exchangeable potassium compounds in sod-podzolic soil. This increase was observed in all variants of the experiment on the soil profile to a depth of 60 cm. Deeper than 60 cm, the difference in the experimental variants was less pronounced, and in relation to phosphorus – almost imperceptible (within the error).

The highest values of phosphorus q potassium content were recorded in the variants with the application of fresh sewage sludge and amounted to 98.5 and 97.2 mg/kg of soil, respectively, mobile phosphorus compounds and exchangeable potassium in the upper (0-20 cm) layer of soil (variant with the highest dose of sewage sludge application – variant 6). In the subsoil (20-40 cm) layer, the difference was also significant in the experimental variants compared to the control, but the content of mobile phosphorus compounds changed to a lesser extent than the content of exchangeable potassium compounds. For applying fertilisers in a dose of $N_{60-90}P_{60-90}K_{60-90}$, the concentration coefficient of phosphorus compounds was 1.01–1.17 in the arable soil layer (0-20 cm), and along the soil profile to a depth of 60 cm increased and varied within 1.17-1.30 (20-40 cm) (see Table 2). The highest values of the concentration coefficients of phosphorus and potassium compounds were recorded in the variants with the introduction of fresh SPS, namely variant 6 (SS - 40 t/ha + $N_{10}P_{14}K_{58}$) and amounted to 1.28 and 2.36 mg/kg of soil, respectively, in the upper (0-20 cm) soil layer. In the subsoil layer (20-40 cm), the concentration of phosphorus and potassium compounds was 1.33 and 2.28, respectively.

Table 2. The impact of sewage sludge and composts based on it on the content of mobile phosphorus compounds and exchangeable potassium compounds in soddy-medium-podzolic soil, the average for 2016-2019

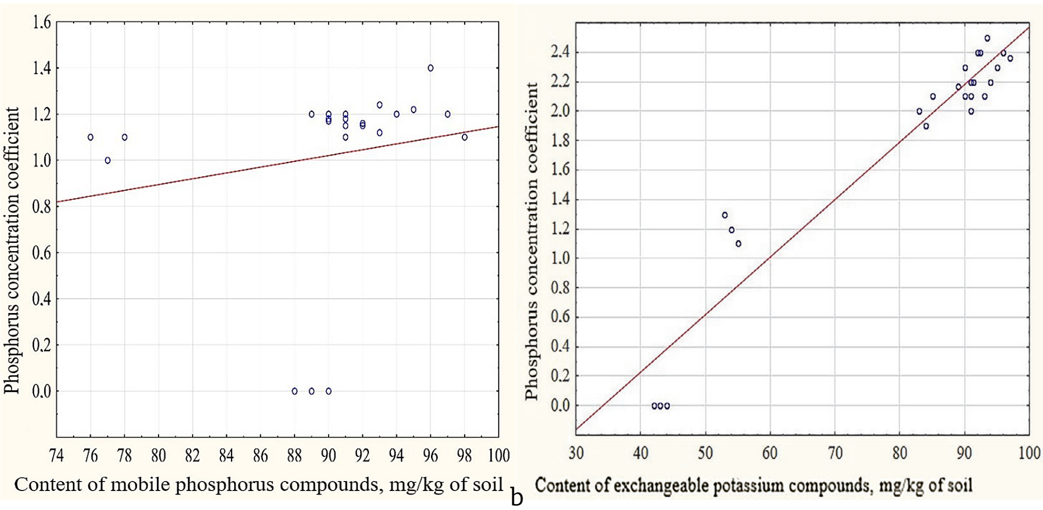
Variant	Soil layer, cm	Content of mobile phosphorus compounds, mg/kg of soil	Content of exchangeable potassium compounds, mg/kg of soil	Compound concentration coefficient P	Compound concentration coefficient K
1. Without fertilisers (control)	0 - 20	62.9	41.2	-	-
	20 - 40	70.3	40.9	-	-
	40 - 60	49.7	37.5	-	-
	60 - 80	30.6	32.2	-	-
2. $N_{60}P_{60}K_{60}$	0 - 20	77.5	53.9	1.01	1.30
	20 - 40	82.2	50.9	1.17	1.24
	40 - 60	53.8	43.6	1.08	1.16
	60 - 80	30.7	36.7	1.00	1.14
3. $N_{90}P_{90}K_{90}$	0 - 20	90.4	83.4	1.17	2.02
	20 - 40	91.7	75.3	1.30	1.84
	40 - 60	60.3	53.8	1.21	1.43
	60 - 80	32.7	35.9	1.07	1.11
4. SS - 20 t/ha + $N_{50}P_{52}K_{74}$	0 - 20	91.2	89.3	1.18	2.17
	20 - 40	92.4	83.1	1.31	2.03
	40 - 60	70.2	56.9	1.41	1.52
	60 - 80	33.7	38.5	1.01	1.20
5. SS - 30 t/ha + $N_{30}P_{33}K_{66}$	0 - 20	93.5	91.8	1.21	2.23
	20 - 40	88.2	88.2	1.25	2.16
	40 - 60	78.5	55.2	1.58	1.47
	60 - 80	34.2	37.6	1.18	1.17
6. SS - 40 t/ha + $N_{10}P_{14}K_{58}$	0 - 20	98.5	97.2	1.28	2.36
	20 - 40	93.7	93.4	1.33	2.28
	40 - 60	82.5	60.3	1.66	1.61
	60 - 80	33.5	38.3	1.09	1.19
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{50}P_{16}K_{67}$	0 - 20	91.2	87.5	1.18	2.12
	20 - 40	88.4	84.4	1.26	2.06
	40 - 60	79.2	57.8	1.59	1.54
	60 - 80	33.7	39.3	1.10	1.22
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{30}K_{55}$	0 - 20	94.2	93.2	1.22	2.26
	20 - 40	90.5	88.9	1.29	2.17
	40 - 60	82.7	59.2	1.66	1.58
	60 - 80	34.6	39.1	1.13	1.21
LSD 0.5, mg/kg of soil	0 - 20	14.8	14.4	0.21	0.27
	20 - 40	10.1	12.1	0.03	0.05
	40 - 60	6.7	8.3	0.01	0.01
	60 - 80	3.5	4.6	0.01	0.01

The use of composts based on SS (variants 7 and 8) provided the concentration coefficients of phosphorus and potassium compounds in the range of 1.10-1.66 and 1.21-2.26, respectively. The lowest concentration coefficients of phosphorus and potassium compounds were observed in the soil profile at a depth of 60-80 cm, due to a decrease in the content of phosphorus and potassium compounds.

According to the correlation and regression analysis, the phosphorus concentration coefficient (Fig. 1) depends mainly on the content of mobile connections in soil with coefficients of determination $R^2 = 0.70$, and correlation $r = 0.73$. The multiple regression equation can be presented as follows:

$$y = -0.1107+0.0126*x,$$

where x – content of mobile phosphorus compounds in soil, mg/kg of soil; *in* – coefficient of phosphorus concentration.



a b

Figure 1. Correlation dependence of the concentration coefficient of phosphorus (a) and potassium (b) on the content of their compounds in sod-podzolic soil.

Based on the correlation and regression analysis, the coefficient of potassium concentration depends most of all on the content of its metabolic compounds in the soil with coefficients of determination and correlation $R^2 = 0.91$, $r = 0.95$. The multiple regression equation can be presented as follows:

$$y = -1.3341+0.0391*x,$$

where, x – content of exchangeable potassium compounds in soil, mg/kg of soil; y – potassium concentration coefficient.

CONCLUSIONS

Application of wastewater sludge in doses of 20-40 t/ha with the corresponding balance dose of mineral fertilisers at the rate of $N_{90}P_{90}K_{90}$ causes a significant increase in the content of the main elements of mineral nutrition in soddy-medium-podzolic soil, in particular, the nitrogen content of alkaline hydrolysed compounds at the level of 51.2-56.5 mg/kg of soil in the upper (0-20 cm) layer and 27.9-31.6 – in the lower (20-40 cm) layer, which, respectively, by 16-24% and 8-18% exceeded the control variant on average for three years of research.

The content of mobile phosphorus compounds and exchangeable potassium in the variants with the application of sewage sludge in the upper 0-20 soil layer ranges from 77.5-98.5 mg/kg of soil and 89.3-97.2 mg/kg of soil and increases under the influence of increasing doses of sewage sludge and composts based on it. Their highest values were recorded in the variant where SS was applied – 40 t/ha and $N_{10}P_{14}K_{58}$ (variant 6), which exceeded the control variant of phosphorus and potassium by 35.4 and 55.9 mg/kg of soil, respectively.

Such a dose of fertilizer application results in the highest concentration coefficient of phosphorus and potassium compounds at the level of 1.28 and 2.36 respectively in the layer of 0-20 cm of soddy-medium podzolic soil. The results of correlation and regression analysis indicate that the dependence of the coefficient of phosphorus concentration in the soil on the content of its mobile compounds is determined by the coefficients of determination $R^2 = 0.70$, and correlation $r = 0.73$, and the potassium concentration coefficient in the soil depends most of all on the content of exchangeable potassium compounds with determination and correlation coefficients $R^2 = 0.91$, $r = 0.95$, respectively.

Thus, in further studies, it is important to determine the trends in the stabilisation of agrochemical parameters of soddy-medium-podzolic soil under conditions of repeated fertilisation of Jerusalem artichoke in permanent culture, and the environmental impact of the use of such types of fertilisers on the soil environment and the conditions of growth and development of the crop.

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Зміни основних агрохімічних властивостей дерново-підзолистого ґрунту після удобрення топінамбура осадом стічних вод

Анотація. Дослідженнями встановлено, що внесення осаду стічних вод та компостів на його основі під топінамбур суттєво впливає на зміну агрохімічних показників дерново-середньопідзолистого ґрунту, сприяючи збільшенню вмісту лужногідролізованих сполук азоту на 2,2-13,4 мг/кг ґрунту порівняно з контролем і визначаючи їх вміст на рівні 51,2-56,5 мг/кг ґрунту у верхньому (0-20 см) та 27,9-31,6 мг/кг ґрунту — у нижньому (20-40 см) шарі. Вміст амонійних сполук азоту у варіантах із внесенням добрив коливався в невеликому діапазоні значень (16-21 мг/кг ґрунту) і зростав під впливом збільшення доз добрив. Поряд зі зміною вмісту нітратного азоту це сприяло збільшенню вмісту мінеральних сполук азоту в ґрунті в межах 18,5-23,4 мг/кг ґрунту в орному (0-20 см) та 19,8-21,9 мг/кг ґрунту - в підорному (20-40 см) шарах, що на 1,7-2,2 мг/кг ґрунту вище контрольного варіанту. Найвищі значення вмісту мінеральних сполук азоту зафіксовано у варіанті, де вносили найбільшу дозу осаду стічних вод — 40 т/га та мінеральні добрива (N10P14K58). Незважаючи на широкий діапазон значень вмісту азоту лужногідролізованих сполук та мінеральних азотовмісних сполук, їх співвідношення залишалося стабільним і становило 2,3-2,6 у верхньому та 1,3-1,5 у нижньому (20-40 см) шарі ґрунту, а також зменшувалося зі збільшенням дози внесення добрив. Тобто цей показник змінювався несуттєво залежно від дози внесення добрив. Вміст рухомих сполук фосфору у варіантах із застосуванням добрив коливався в межах значень (77,5-98,5 мг/кг ґрунту) і зростав під впливом осаду стічних вод та компостів на його основі, що перевищувало контрольні значення на 14,6-35,6 мг/кг ґрунту. Найвищі показники вмісту рухомих сполук фосфору зафіксовано у варіанті з внесенням осаду стічних вод — 40 т/га та N10P14K58,10P14K58. Внесення осаду стічних вод у дозі 20-40 т/га сприяло підвищенню вмісту обмінних сполук калію на рівні 89,3-97,2 мг/кг ґрунту у верхньому (0-20 см) та 83,1-93,4 мг/кг ґрунту — у нижньому (20-40 см) шарі, що на понад 42,1 мг/кг ґрунту перевищувало контрольний варіант. Меншою мірою вміст обмінних сполук калію збільшувався при внесенні компостів на основі осаду стічних вод та соломи. Кореляційно-регресійний аналіз свідчить, що коефіцієнт концентрації фосфору в ґрунті найбільшою мірою залежить від вмісту його рухомих сполук з коефіцієнтом детермінації R^2 = 0,70. Коефіцієнт концентрації калію тісно (R^2 = 0,91) корелює з вмістом його обмінних сполук у ґрунті

Ключові слова: ґрунт, фракція, азот, фосфор, калій, коефіцієнт концентрації, кореляційно-регресійний аналіз