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Sewage Sludge as a Component to Create a Substrate for Biological Reclamation

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ABSTRACT

The main ways of sewage sludge disposal in the European Union and Ukraine were considered. The main problems of sludge utilization in Ukraine were identified. Research on the possibility of using a substrate based on sewage sludge for biological reclamation of disturbed lands was conducted. The quality of the sludge from Lviv WWTP was determined. The best substrate composition for biological land reclamation was determined by using bioindication. It was established that the use of settled sludge observed inhibition of plant growth and development. Introducing additional components to the substrate, in the form of sorbents, makes it possible to increase the content of sewage sludge. Positive changes in plant growth and development when using a soil-based substrate, sewage sludge and sorbent were observed.

Keywords: sewage sludge, bioindication, substrate, utilization, sorbent, settled sludge.

INTRODUCTION

Sewage sludge is the main by-product of wastewater treatment in wastewater treatment plants, which is formed on the primary, secondary and tertiary stages of water treatment. It belongs to the group of biodegradable waste (biowaste), which means that these wastes can undergo anaerobic digestion and aerobic decomposition.

Today, there is a global increasing trend towards the formation and accumulation of sewage sludge, which gives priority to its environmentally safe and sustainable management. According to [Formation and management…, 2020, Fytili & Zabaniotou, 2008], about 3 Mt of sewage sludge are produced annually in Ukraine, the European Union produces 10 Mt.

Over the past decade, the European Union, unlike Ukraine, has reached considerable experience in the treatment of the waste generated from wastewater treatment plants. This became possible by the adoption and implementation of several relevant rules and laws, Council Directive 86/278 / EEC and Council Directive 91/271 / EEC. The European Union's target to reduce final waste disposal by 50% by 2050 [Fytili & Zabaniotou, 2008].

The European Union used many technologies for treating sewage sludge that are associated with the final disposal methods. The most common methods in the European Union include aerobic and anaerobic digestion. Anaerobic digestion is most used in Spain, the United Kingdom, Italy, Finland and Slovakia, whereas aerobic digestion is the prevailing technology in the Czech Republic and Poland [Kelessidis & Stasinakis, 2012]. According to studies, using the technology of aerobic digestion of sewage sludge in large quantities, humic acids are formed in their composition, and under anaerobic technology – the main components of sewage sludge are proteins and aromatic amino acids [Du & Li, 2017].

Sewage sludge is rich in organic matter and nutrients, such as nitrogen, phosphorus and potassium, and thus it is an attractive material that can be used in agriculture as a fertilizer or as a component to improve soil quality. However, sewage sludge tends to accumulate and concentrate heavy metals, organic contaminants and pathogenic organisms. The presence of such compounds, as well as excess nitrogen and phosphorus, presents a challenge in selecting the method of sludge disposal, both from an economical and environmentally perspective [Twardowska et al., 2004, Fijalkowski et al., 2017, Nebesnyi et al., 2019, Moroz et al., 2020]. The use of sludge in agriculture is one of the most common methods of disposal in many EU countries. This method is mostly used in France, Spain and the UK [Mininni et al., 2014].

Another common method of sludge disposal is its combustion. Currently, more than 450 thermal drying plants operate in the EU, more than half of which are in Germany, Italy, France and the United Kingdom [Kelessidis & Stasinakis, 2012]. The use of this method allows obtaining ash, which can be used to produce building materials [Tymchuk et al., 2020]. It should also be noted that for many years in Sweden and Finland, sewage sludge has been used for land reclamation of disturbed industrial development. According to the data [Di Bonito, 2008], the use of sludge in a mixture with lime has a positive effect on the remediation of landfills and spent coal mining quarries.

Unlike the European Union, the situation with sewage sludge in Ukraine is critical, as we do not have an appropriate national strategy that could resolve the problem of formed sludge and accumulated on the silt fields. Currently, several regulations in Ukraine address the use of sewage sludge in agriculture [Law of Ukraine…, 2002, Law of Ukraine…, 2019, DSTU 8727, 2017].

Today, Ukraine has accumulated more than 5 billion tons of sewage sludge and as mentioned above, another 3 Mt have added annually, of which only 5% is used as secondary raw material [Astrelin, 2010]. Agriculture accounts for the largest share of sewage sludge use. Studies show that when using sewage sludge as organo-mineral fertilizers, an increase in the growth of some agricultural plants can be observed, for example, with the application of such fertilizers in the amount of 500-600 kg/ha, corn growth increases by an average of 33.5%, rapeseed – 24%, etc. [Rudnytskyi, 2013].

Moreover, reconstruction of treatment plants is planned in some large cities of Ukraine, which in the future will allow the reduction of the sewage sludge output. For example, in Lviv, it is planned to build a biogas station where fresh sludge will be fermented. As a result of this process, biogas can be used to produce electricity and heat [Kizieiev et al., 2016].

Block 2 and 3 will be reconstructed at the Bortnitskaya Aeration Station in Kyiv, which envisages the construction of gravity and mechanical sludge seals for thermal sludge utilization. As a result, the wastewater treatment plants will receive ash, which can be used for the manufacture of building materials.

Given the above, an important issue for Ukraine is to find new ways of sewage sludge disposal, one of which, for example, could be the use of a

Table 1. Types of plants that are used to restore disturbed areas

Type of plants	Influence, benefit
Ailanthus altissima (Heaven tree)	Mixed forest facilitated C sequestration
Alnus glutinosa (Common alder)	Stimulation of microbial communities and soil recovery
Cercis canadensis (Eastern redbud)	Promote early succession
Dalbergia sissoo (Indian rosewood)	Soil recovery, bioreclamation
Eucalyptus camaldulensis (Eucalyptus)	Increased diversity of mycorrhiza and other rhizospheric fungi
Fraxinus spp. (ash)	Biomass growth
Larix decidua (European larch)	Altered microbial biomass
Liriodendron tulipifera (Yellow poplar)	Biomass growth
Pinus tabuliformis (pine)	Mixed forest facilitated C sequestration
Pinus sylvestris (Scots pine)	Stimulation of microbial communities and soil recovery, biomass growth
Populus suaveolens (Hybrid poplar)	Biomass growth
Ulmus pumila (Siberian elm)	Mixed forest facilitated C sequestration
Quercus spp. (oaks)	Biomass growth
Quercus robur (Common oak)	High carbon sink after 34 years of growth

substrate for biological reclamation of technologically disturbed lands (landfills, waste heaps, etc.).

Land reclamation is a lengthy and difficult process, as it requires considerable economic and energy costs. The most difficult process at the stage of biological land reclamation is to choose the direction of reclamation, as well as to support the necessary plants for the overgrowing of the territory and the use of mineral fertilizers. Today, much attention has been paid to forest and agricultural land reclamation, since over the last few years the area of forests and fertile soil in the world has declined. The mining activity has the greatest negative impact on the physicochemical properties of the soil and survival of the plants; , in this regard, such lands can be restored by sowing such species of plants that can carry the specific properties of the soil within the mine workings. Table 1 presents some plant species that are used for land reclamation [Borišev et al., 2018, Tymchuk et al., 2021]. It is possible that sewage sludge will be used for the stage of biological reclamation of the closed Lviv municipal landfill [Savchyn et al., 2020]. Our work consisted in investigating the possibility of using a substrate based on sewage sludge for biological land reclamation.

MATERIALS AND METHODS

Studies were carried out on the sewage sludge from Lviv municipal wastewater treatment plant (WWTP), using fresh and settling (stored in a sealed medium for 6 months, to simulate the conditions of sludge accumulation on sludge sites) sludge.

Bioindication was carried out based on the application and adaptation of the State Standards (DSTU ISO 11269-1, 2004, DSTU ISO 11269-2, 2002). This method is suitable for all soils, soil-forming materials, deposited waste, or chemicals that can be incorporated into the soil. According to this technique, the growth substrates are the soil to be studied and the control soil, which is known to be of good quality. Two kinds of plants belonging to one category were chosen for the experiment. Category 1 – monocotyledonous plants: rye, rice, oats, wheat, barley, common sorghum, corn. Category 2 – Dicotyledones: white mustard, rape, radish and wild rape, Chinese cabbage, garden cress, tomato, and beans. Before using the seeds of each culture, an analysis was made, and the energy of their germination was determined. Ten identical seeds of the selected species were planted into each vessel. In order to

Table 2. Results of research of qualitative parameters of sewage sludge

Indicators	Units of measurement	Actual value	
		Dry substance	Natural humidity
Acidity: pH salt	pH	–	6.4
pH water	pH	–	6.1
Moisture	%	–	73.6
Ash	%	23.8	–
Total Phosphorus	%	1.6	0.42
Total potassium	%	0.3	0.08
Total nitrogen	%	3.56	0.93
Ammonium nitrogen	%	0.28	0.073
Nitrogen nitrate (in peat)	mg/100г	11.75	–
Calcium (as soil)	mmol/100г	11.75	–
Magnesium (as soil)	mmol/100г	4.12	–
Sulfur mobile (in the soil)	mg/kg	14.8	–
Minerals: copper (Cu)	mg/kg	–	4.0
zinc (Zn)	mg/kg	–	17.6
manganese (Mn)	mg/kg	–	45.1
cobalt (Co)	mg/kg	–	2.86
iron (Fe)	mg/kg	–	65.0
lead (Pb)	mg/kg	–	1.56
cadmium (Cd)	mg/kg	–	0.20
boron (B)	mg/kg	–	4.01

define the feasibility of using sewage sludge for study, the determination of qualitative indicators of these sediments was carried out. For this purpose, the qualitative indicators of sewage sludge were defined on the certified equipment in the laboratory agrochemical, toxicological and radiological studies of soil environmental safety and quality control of Lviv branch of the State institution "Soils protection institute of Ukraine"; they are presented in Table 2.

The presented data show that there is a significant amount of the main nutrient elements (N – 3.56, P – 1.6, K – 0.3 %), macro- and trace elements in the sewage sludge, as well as the available content of the organic constituent (23.8%), which can provide nutrients to most plants. The content of heavy metals in the samples studied did not exceed MPC.

The research was conducted in three stages:

Stage 1: Two experiments were carried out on settled sludge (fresh sludge sample was stored without oxygen for 6 months to simulate the conditions for waste dumping on sludge sites), to which normal dark gray soil was added.

In the first experiment, the settled sludge and soil were mixed in proportions of (%): 100:0; 80:20; 60:40; 40:60; 20:80; 0:100. On the created substrate, bioindication was performed by planting 10 seeds of common barley (*Hordeum vulgare*), white mustard (*Sinapis alba*) and garden cress (*Lépidium sativum*) in Petri dishes. The experiments were carried out in a fourfold repetition.

In the second experiment, settled sludge, thermally treated settled sludge (2 h at t = 105 ℃) and soil were mixed in proportions of (%): 60:40; 20:80; 0:100. Bioindication was carried out in Petri dishes by planting 10 seeds of common barley into a substrate with heat-treated sludge, and 10 seeds of common barley etched with Vitawax 200 FF, v.t.s. (normal consumption of 3 l/ton of seed). The experiment was carried out in a triple repetition.

Stage 2: The study was conducted on fresh sludge to which the dark gray soil was added in ratio of (%): 100: 0; 80:20; 60:40; 40:60; 20:80; 0: 100. Bioindication was carried out in Petri dishes, planting 10 seeds of common barley, etched barley (Vitawax 200 FF) and garden cress. The experiment was carried out in a fourfold repetition.

Stage 3: The study was conducted with fresh sewage sludge, to which dark gray podzol soil was added in the amount (%): 0; 20; 25; 30; 35; 40, and additionally added sorbent in the amount (%): 5; 7,5; 10. On the created substrate, 10 seeds of common barley were planted. The experiments were carried out in a triple repetition.

During the experiment, the following indicators were observed: the time of appearance of sprouts, their number for each day, the total germination. After the research, the length and mass of the above-ground part and the roots were measured.

RESULTS AND DISCUSSION

After conducting two experiments of stage 1 of the research the following results were obtained:

- in the first experiment (with settled sludge) in all variants, except control, germination of plants was not observed in any sample.

Fig. 1. The presence of fungi and pathogenic microflora in the studied samples

– in the second experiment (thermally treated and settled sludge), an identical situation was observed, the use of etched seeds also did not give results, germination of plants was not observed except for the control.

In both cases, in the studied samples the development of fungi and pathogenic microflora was observed (Fig. 1). The results of stage 2 of the study are shown in Table 3.

As can be seen from the table, the relatively acceptable amount of sewage sludge in this substrate is ≈ 20%, since, in all bioindication plants, the number of sprouts at the end of the experiment was not different from the control (etched barley – 17.5 %, garden cress – 15 %), and in the samples with unetched barley, in general, exceeded it (by 2.5%). However, it should also be noted that in the initial stages of the study, there was a delay in the appearance of sprouts during the first 7 days.

After the experiment, the effect of the substrate on the growth and development of plants was determined, and the measurement results are presented in Table 4.

The results of the dependence of changes in plant growth and development depending on the substrate used to show that, when the content of sewage sludge in the substrate is 20%, the average weight of plants is not significantly different from the control and varies within +5.4 to -9.1%, whereas the difference in length is more significant and reaches: for the ground part from +9.0 to -30.5%, and roots from -19.9 to -57.1%.

When used in the substrate 40% of the sewage sludge, there was a much greater impact on

Table 3. The data of germination of bioindicators in the investigated substrates

Date	Option (soil:SS)	The similarity of experimental plants, %											
		Etched barley				Common barley				Garden cress			
26.09 2nd day	Control	70	90	90	90	100	100	100	80	100	90	60	90
	Substrate 80:20	30	20	20	60	90	80	90	100	-	-	-	-
	Substrate 60:40	-	-	-	-	10	-	-	-	-	-	-	-
28.09 4th day	Control	90	80	100	90	100	100	100	80	100	100	60	100
	Substrate 80:20	40	20	40	60	100	90	90	100	-	10	10	60
	Substrate 60:40	-	-	-	-	20	-	-	-	-	-	-	-
01.10 7th day	Control	90	90	100	100	100	100	100	80	100	100	70	100
	Substrate 80:20	60	50	70	80	100	90	100	100	60	70	70	90
	Substrate 60:40	-	-	-	-	20	20	10	10	-	-	10	-
03.10 10th day	Control	90	90	100	100	100	100	100	80	100	100	70	100
	Substrate 80:20	60	80	80	90	100	90	100	100	70	70	80	90
	Substrate 60:40	-	-	-	-	20	20	20	10	-	10	20	-

Table 4. Changes in the growth and development of plants, depending on the use of different types of substrates

Variant	The average height of the ground part of the plant, cm	Average root length, cm	Average weight, g	The average weight of the ground part of the plant, g	The average weight of roots, g
Etched barley					
Control	10.83	18.19	0.239	0.155	0.084
Substrate 1 (80:20)	8.51	11.12	0.252	0.147	0.105
Substrate 2 (60:40)	-	-	-	-	-
Common barley					
Control	11.76	19.02	0.286	0.168	0.119
Substrate 1 (80:20)	12.82	15.24	0.260	0.165	0.095
Substrate 2 (60:40)	8.73	6.64	0.233	0.185	0.048
Garden cress					
Control	4.36	5.31	0.0225	-	-
Substrate 1 (80:20)	3.03	2.28	0.0205	-	-
Substrate 2 (60:40)	1.98	0.65	-	-	-

Table 5. Data of germination of biondicators in the investigated substrates

Date	Option (soil:SS)	The similarity of experimental plants, %											
		0% zeolite			5% zeolite			7.5% zeolite			10% zeolite		
27.10 4th day	Control	60	90	90	80	50	80	70	70	60	60	60	-
	Substrate 80:20	60	90	60	30	50	80	50	50	30	20	-	20
	Substrate 75:25	40	40	70	70	80	30	30	60	30	-	10	10
	Substrate 70:30	-	20	20	60	50	40	10	40	30	-	-	-
	Substrate 65:35	-	-	-	40	10	-	20	30	30	20	-	-
	Substrate 60:40	-	40	-	10	-	-	20	10	-	10	10	10
29.10 6th day	Control	90	100	100	100	90	100	100	100	90	100	100	90
	Substrate 80:20	80	90	90	80	80	100	90	100	90	90	100	90
	Substrate 75:25	40	80	80	100	100	90	90	90	80	100	90	80
	Substrate 70:30	30	40	40	80	90	80	70	100	80	100	80	80
	Substrate 65:35	40	20	-	50	70	30	70	90	70	100	80	80
	Substrate 60:40	-	40	-	20	10	10	50	90	60	90	50	70
31.10 8th day	Control	90	100	100	100	90	100	100	100	100	100	100	100
	Substrate 80:20	100	90	90	80	100	100	90	100	90	90	100	90
	Substrate 75:25	50	80	90	100	100	90	100	90	90	100	90	100
	Substrate 70:30	30	40	50	80	90	80	70	100	90	100	80	100
	Substrate 65:35	40	20	-	60	70	50	70	90	90	100	90	100
	Substrate 60:40	-	40	-	20	20	10	60	100	80	100	50	80
02.11 10th day	Control	90	100	100	100	90	100	100	100	100	100	100	100
	Substrate 80:20	100	90	90	90	100	100	90	100	100	90	100	90
	Substrate 75:25	70	80	90	100	100	90	100	90	90	100	100	100
	Substrate 70:30	40	60	50	100	90	80	90	100	90	100	90	100
	Substrate 65:35	50	20	-	60	90	50	70	90	90	100	90	100
	Substrate 60:40	10	60	-	20	20	10	70	100	80	100	60	90

plant growth and development, namely: average weight of plants -18.5%, the height of the ground part from -25.8 to -54.6%, root length from -65, 1 to -87.8%.

Stage 3 of the study allowed us to test the possibility of adding sorbents to the composition to improve the properties of the substrate. According to the previous studies, the content of sewage sludge in the substrate did not exceed 40%. The results of bioindication are shown in Table 5.

The results presented in the table show that the addition of sorbents to the composition significantly improved the germination of plants. As can be seen, in the samples without sorbent

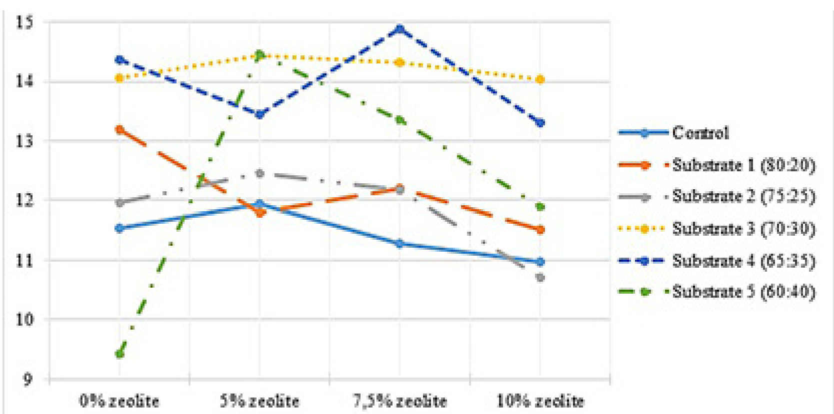

Fig. 2. Dependence of change of growth of ground part of plants depending on substrate

addition the germination of plants was worse than in the sorbent-added samples. Thus, the best germination rates were observed in the substrate with a sludge content of 40% and an amount of sorbent of 7.5% and 10%, and as can be seen at the end of the experiments the number of bioindicator plants sprouts was practically different from the control and was identical in two variants (-16.6 %). For example, in the samples without sorbent and 5% content, this figure was -75.9% and -82.7%, respectively. Moreover, it should be noted that during the first four days, the germination of plants in the samples with a sorbent content of 10% was worse than other samples.

After the study was conducted, the effect of the substrate on the growth and development of plants was determined; the measurement results are presented in Table 6. Figure 2 shows the dependence of the growth of the ground part of plants depending on the substrate.

As shown in the figure, the average height of the ground part of the plants is higher than the control samples and varies within:

- with a sorbent content of 0% – from -18.4 to +24.4%;
- with a sorbent content of 5% – from -1.09 to +20.2%;
- with a sorbent content of 7.5% – from +7.9 to +31.8%;
- with a sorbent content of 10% – from -2.4 to +27.8%.

Moreover, the best growth rates of the ground part were observed in the substrate with a sludge content of 35% and a sorbent content of 7.5%.

Figure 3 shows the dependence of the growth of the root of the plants on the substrate.

Table 6. Changes in the growth and development of plants, depending on the use of different types of substrates

Variant	The average height of the ground part of the plant, cm	Average root length, cm	Average weight, g	The average weight of the ground part of the plant, g	The average weight of roots, g
0% zeolite					
Control	11.55	15.64	0.321	0.185	0.136
Substrate 1 (80:20)	13.18	16.83	0.475	0.185	0.290
Substrate 2 (75:25)	11.97	15.11	0.494	0.199	0.295
Substrate 3 (70:30)	14.07	14.20	0.601	0.261	0.340
Substrate 4 (65:35)	14.37	12.86	0.478	0.269	0.209
Substrate 5 (60:40)	9.43	12.33	0.321	0.151	0.170
5% zeolite					
Control	11.94	18.25	0.413	0.216	0.198
Substrate 1 (80:20)	11.81	17.15	0.493	0.196	0.296
Substrate 2 (75:25)	12.47	17.41	0.428	0.181	0.248
Substrate 3 (70:30)	14.43	17.66	0.421	0.217	0.204
Substrate 4 (65:35)	13.45	14.66	0.459	0.224	0.235
Substrate 5 (60:40)	14.47	13.23	0.368	0.200	0.168
7,5% zeolite					
Control	11.29	18.27	0.432	0.195	0.237
Substrate 1 (80:20)	12.21	17.33	0.428	0.175	0.254
Substrate 2 (75:25)	12.18	15.68	0.352	0.161	0.190
Substrate 3 (70:30)	14.33	16.78	0.456	0.224	0.232
Substrate 4 (65:35)	14.88	17.57	0.447	0.213	0.234
Substrate 5 (60:40)	13.36	14.05	0.394	0.196	0.198
10% zeolite					
Control	10.98	17.08	0.506	0.182	0.323
Substrate 1 (80:20)	11.51	16.74	0.439	0.178	0.261
Substrate 2 (75:25)	10.72	14.55	0.376	0.177	0.199
Substrate 3 (70:30)	14.03	18.28	0.437	0.195	0.242
Substrate 4 (65:35)	13.31	17.10	0.453	0.203	0.250
Substrate 5 (60:40)	11.90	15.24	0.337	0.146	0.191

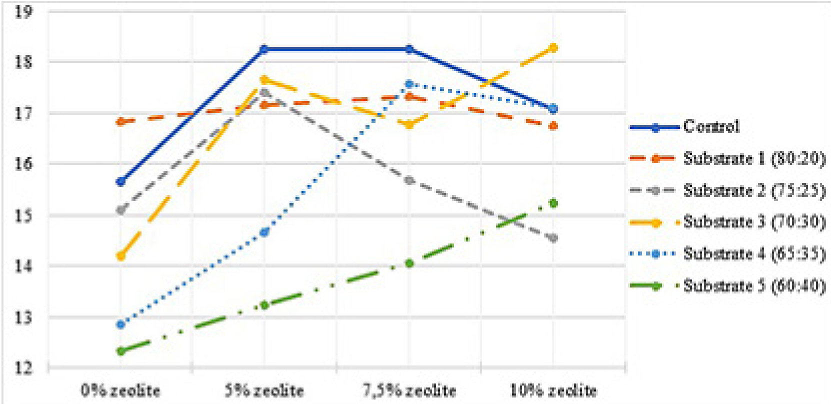

Fig. 3. Dependence of change in growth of root part of plants on substrate

The average length of the roots of the plants is slightly smaller than the control samples and varies within:

- with a sorbent content of 0% – from -21.2 to +7.6%;
- with a sorbent content of 5% – from -27.5 to -3.2%;
- with a sorbent content of 7.5% – from -23.1 to -3.8%;
- with a sorbent content of 10% – from -14.8 to +7.02%.

As can be seen, the root length in all samples was shorter than in the control samples, and only in the substrate with a sediment content of 30% and a sorbent content of 10%, it exceeded the reference values by 7%.

Figure 4 shows the dependence of the change in plant mass depending on the substrate. The average weight of the plants is greater than the control samples and varies within:

- with a sorbent content of 0% – from 0 to +87.2%;
- with a sorbent content of 5% – from -10.9 to -19.4%;
- with a sorbent content of 7.5% – from -18.5 to +5.6%;
- with a sorbent content of 10% – from -33.4 to -10.5%.

As can be seen, the largest changes in mass were observed in the samples with a sediment content of 30% and a sorbent content of 0%, where the average weight of the plants exceeded the reference values by 87.2%. Moreover, positive changes in the weight gain of plants were observed in the samples with a sediment content of 30% and a sorbent content of 7.5% and exceeded the control values by 5.6%.

CONCLUSIONS

Thus, the results obtained indicate that the studied sludge of the Lviv WWTP contains a significant proportion of nutrients and can be used as

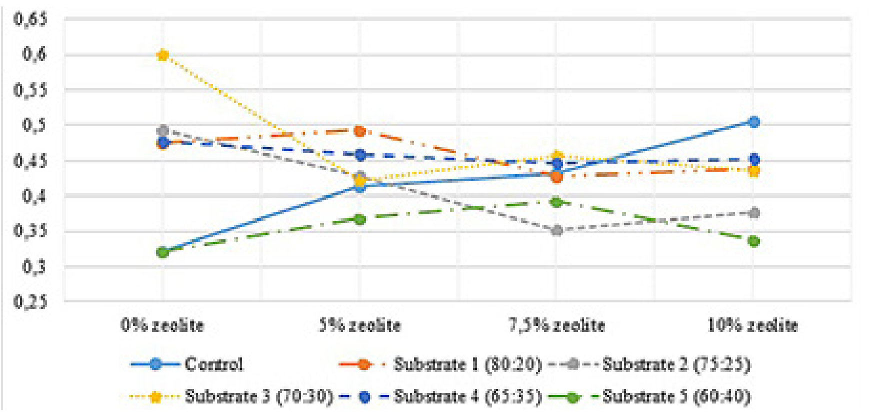

Fig. 4. Dependence of change of weight of plants depending on substrate

a component to create a substrate. However, there is a problem with the settled sludge, as even 20% of the sludge in the substrate had a detrimental effect on the growth and development of plants.

The use of fresh sludge did not cause such negative changes, and in some cases, even exerted a positive effect on the growth and development of plants. Moreover, when adding other components (sorbents) to the substrate, there is an improvement in the qualitative growth of the substrate. For example, when added to the substrate sorbents in the amount of even 5%, it is possible to increase the sludge content to 40%, and when adding 10% sorbents in some cases, there are even more noticeable positive changes in the growth and development of plants.

Our studies have shown that a substrate based on sewage sludge and sorbents can be used for biological land reclamation. Thus, it is possible to solve the problem of reducing the accumulation of waste treatment plants, as well as reduce the cost of the reclamation process.

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