Innovative creation technologies for the growth substrate based on the man-made waste – perspective way for Ukraine to ensure biological reclamation of waste dumps and quarries

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Abstract: This article deals with the problem of man-made waste utilisation, namely, sewage sludge after the biological treatment stage. The current states of the problem in Ukraine and possible ways of its solution are analysed. The connection of research topics with the National Waste Management Strategy of Ukraine is shown. Critical analysis of sewage sludge utilisation technologies was performed. It is proposed to create a growth substrate as an inexpensive and effective alternative to utilise wastes with organic components. The composition of the growth substrate was selected to ensure its functional properties and low cost. The growth substrate was tested using bioindication and further modified by the addition of natural sorbents. The perspectives of the developed innovative technology for biological reclamation of disturbed lands and perspective directions of new researches are considered.

Keywords: man-made waste; sewage sludge; bioindication; substrate; natural sorbents.

Reference to this paper should be made as follows: Tymchuk, I., Malovanyy, M., Shkvirko, O., Zhuk, V., Masikevych, A. and Synelnikov, S. (2020) 'Innovative creation technologies for the growth substrate based on the man-made waste – perspective way for Ukraine to ensure biological reclamation of waste dumps and quarries', *Int. J. Foresight and Innovation Policy*, Vol. 14, Nos. 2/3/4, pp.248–263.

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1 Introduction

Landfills of Ukraine today are powerful sources of environmental hazards. Unlike solid household waste landfills (which are practically absent in Ukraine), waste dumps are not engineering structures and, accordingly, they do not have systems of the leachate treatment and biogas collection and disposal, an anti-filtration screen, the collection and removal systems for the surface runoff. Moreover, no technical and biological reclamation of the garbage-filled sites is carried out. Therefore, the only rational way that will ensure in the future environmental protection in Ukraine is the development and implementation of a comprehensive solid waste management strategy.

Waste storage in the period of preparation for the closure of a solid household waste landfill should serve not only as a method of disposal, but also as a component of a comprehensive approach to the reclamation of the landfill. The use of waste as one of the elements of the hill slope reinforcement, in addition to its disposal, will reduce the costs of reclamation. In areas that will not be used and where no freight traffic is envisaged, technical reclamation in accordance with the requirements of the Ukrainian State Construction Regulations V.2.4-2-2005 'Landfills for municipal solid waste' (chapter 'Land reclamation after the landfill closure', paragraphs 3.115–3.133) should be realised for the following layers:

- Mineral protective layer with water permeability less than 10^{-9} m/s and a thickness of 1 m.
- A layer of synthetic waterproofing membranes at least of 3 mm thick, resistant to chemical and biological aggression and to damage by rodents.
- Drainage layer 0.5 m thick, which serves for the surface runoff removal from the landfill.
- Reclamation layer not less than 1 m, which has a layer of fertile soil of 30–50 cm.

It should be noted that the rules for technical reclamation in accordance with the requirements of the SCR of Ukraine V.2.4-2-2005 are similar to those of Directive 2008/98/EC. The exception is that EU Directive does not require the synthetic waterproofing layer, and does not standardise the fertility of the upper reclamation layer. The present status of waste management planning in Ukraine and main concepts of the Ukrainian National Waste Management Strategy are described in details in Section 2.

Similar problems arise in the planning of technical and biological reclamation of worked out quarries and other lands disrupted by the mining industry. In Ukraine 1063 spoil-heaps were formed, about 15–20% of which are combustible. They occupy an area of 7,188 ha, where about 1.7 billion m^3 of waste rock is stored. To ensure the biological reclamation of waste rock, a nutrient medium is necessary which can be provided by the process of organic-containing waste disposal. Successful biological reclamation requires the creation of a growth substrate.

It is important to use a growth substrate for afforestation of areas affected by uncontrolled deforestation. This problem is especially relevant for the areas characterised by scarce fertile soil resources necessary for afforestation. Such territories include the Ukrainian Carpathians, which have been particularly affected by uncontrolled deforestation (Masikevych et al., 2015). For these purposes, it would be rational to use a growth substrate with local organ-containing wastes of natural and anthropogenic origin in its composition.

Thus, the creation of a fertile reclamation layer is an important problem that will allow in the future ensuring the successful biological reclamation of landfills and lands disturbed by mining operations, as well as afforestation of areas damaged by uncontrolled deforestation. The use of man-made waste as a substrate could be a promising innovative technology. On the one hand, it would ensure the disposal of wastes, which cover large areas and pose a significant environmental threat, and on the other hand, would significantly reduce the need for fertile soils that can be used for biological reclamation purposes. The most common man-made wastes that can be used for biological reclamation are native sewage sludge (used for biological sewage treatment at sewage treatment plants); digested activated sludge (after fermentation for biogas production); spent biomass (in the process of biogas production) and livestock wastes by combining them with natural zeolites and other soil components. The purpose of this research is to investigate the technology for the production of the growth substrate using the sewage sludge.

For technical and economic reasons, most wastewater treatment plants (WWTP) in Ukraine are unable to dispose the municipal sewage sludge. As a consequence, it is accumulated in unacceptably large quantities on drying beds. According to the rough estimate, the total amount of deposited sewage sludge at the Ukrainian WWTPs is over 5 million tonnes of dry matter. When accumulating on the drying beds, they cause the emergency ecological situations in the areas nearby the WWTPs (fires, emissions of greenhouse gases and groundwater contamination as a result of uncontrolled decomposition of the organic component). We propose to use sewage sludge for production of the substrate to provide biological reclamation of disturbed lands. Reclamation areas can be used in the future to install solar power plants or to grow energy crops. Technical aspects of the sewage sludge accumulation at Ukrainian WWTPs and possible ways of its utilisation are discussed in Section 3.

Subsequently, the sewage sludge is considered in the context of the environmental threat posed by its accumulation on drying beds, as well as from the standpoint of using it as a component of the growth substrate. In Section 4 the results of experimental investigation of the growing seedlings on the substrate, based on the municipal sewage sludge are presented. Prospects of using the proposed innovative technology for biological reclamation of disturbed lands are discussed in Section 5.

2 National Waste Management Strategy in Ukraine

The National Waste Management Strategy was adopted on 8 November 2017 by the Decree of the Cabinet of Ministers of Ukraine (2009). The strategy is created to resolve the critical situation with the formation, accumulation, storage, recycling, and disposal of various types of waste [household (Malovanyy et al., 2018), industrial (Plyatsuk et al., 2018), hazardous (Vambol et al., 2017), agricultural (Pavlychenko and Borysovs'ka, 2012), food (Sklyar et al., 2019), tourist (Kinash et al., 2018) and others]. The problem of wastes disposal in Ukraine is of particular magnitude and importance due to the domination of resource-intensive multi-waste technologies in the national economy and the lack of adequate response to its challenges for a long time. The large scale of resource utilisation and energy and raw material specialisation of the national economy together with the outdated technological base have defined and continue to define high indicators of waste generation and accumulation.

Such circumstances lead to the deepening of the ecological crisis and exacerbation of the socio-economic situation in society. They necessitate the implementation of reforms taking into account the national and world experience of the whole legal and economic system regulating the use of natural resources in general and waste management in particular. The waste management is one of the key environmental problems and more significant in terms of resources.

The waste generated in the process of extraction, enrichment, chemical-metallurgical processing, transportation and storage of minerals is a secondary raw material for industry, construction and power engineering. Waste, which is a residue of final consumption products (waste paper, polymers, cullet, used tires, etc.), also represent a significant resource potential.

The high level of waste generation and the low level of its use as the secondary raw material in Ukraine have led to the accumulation of significant amounts of solid waste each year, only a small fraction of which is used as the secondary material resources, and the rest falls into landfills.

The difference between the waste situation in Ukraine and other developed countries is the large volume of generated waste, insufficient funding and corresponding lack of infrastructure for the waste management. The presence of such infrastructure is an indispensable feature of all economies of developed countries.

In general, the waste management system in Ukraine is characterised by the following trends:

- the accumulation of waste in both the industrial and household sectors, which has a negative impact on the environment and human health
- improper disposal and utilisation of hazardous waste
- disposal of household waste without taking into account possible dangerous consequences
- improper use of waste as a secondary raw material due to the lack of organisational and economic foundations
- inefficiency of implemented economic instruments in the waste management.

The significant amounts of waste accumulated in Ukraine and the lack of effective measures to prevent their generation, recycling, neutralisation and disposal deepen the ecological crisis and hinder the development of the national economy.

This situation necessitates the creation and maintenance of the proper national system for preventing waste generation, collection, recycling, neutralisation and environmentally sound disposal. This should be an urgent task even in the context of the relative limited economic capacity of both the state and major waste producers. Thus, the only possible way to resolve the situation is to create a comprehensive waste management system.

Solving this problem is crucial in addressing the issues of energy and resource independence of the state, saving natural material and energy resources, and an urgent strategic task (priority) of public policy.

The strategy identifies the main areas of government regulation in the field of waste management in the coming decades, taking into account European approaches to waste management. The National Waste Management Plan till 2030 was developed in accordance with the strategy (Cabinet of Ministers of Ukraine, 2019). According to this plan, the reclamation of landfills and waste dumps which do not meet the established requirements is provided. Regarding the sewage sludge, the National Waste Management Plan foresees the creation of new facilities and the capacity increase of existing sewage sludge treatment facilities by the operators of municipal sewage treatment facilities. Thus, the conducted researches fully meet Ukraine's national goals of harmonising the waste management system with EU standards and regulations.

3 Analysis of environmental threat of sewage sludge accumulation and possible ways of its use

One of the important problems regarding the environmental protection is the problem of formation and accumulation of sewage sludge, which is formed at municipal WWTPs. Every year this problem becomes more urgent not only in Ukraine but also in many countries of the world and requires immediate solution, since storage of sewage sludge on sludge drying beds makes them a source of bacterial and toxicological risk (Zasidko et al., 2017).

The utilisation of sewage sludge is one of the most expensive stages, which usually accounts for 50% of the total operating costs for sewage treatment plants. So the use of cost-effective methods of sewage sludge treatment is one of the most important issues for management (Zhen et al., 2017).

Currently, several methods of sewage sludge utilisation are known: disposal, composting, burning, drying, use in agriculture, anaerobic digestion and processing to manufacture the building materials (Kelessidis et al., 2012).

In developed countries of the European Union, such as Portugal, Ireland, the UK and Spain, approximately 70% of sewage sludge is used in agriculture. In the USA 47% of sludge are disposed, in Japan 52% are used for the manufacture of building materials (Zhen et al., 2017; Mininni et al., 2014).

Unlike other countries, in Ukraine the situation with the formation and accumulation of sewage sludge is catastrophic one. According to Astrelin (2010), the total amount of accumulated sludge is more than 5 billion tons, and another 3 million tons are added annually. The area covered with sludge is more than 33,000 hectares, and only 3–5% of sludge is used as a secondary raw material.

In most cases the problem of sludge utilisation occurs due to the fact that processing lines of WWTP do not adjusted for the processing of sewage sludge, and this situation is typical for all WWTPs in Ukraine (Klius et al., 2018).

Today, the drying beds at Ukrainian WWTPs occupy large areas and are overfull. For example, in the City of Kharkiv at the WWTP #2 about 6 mln. m^3 of sludge are accumulated on the area of 126 ha; in Kyiv at the Bortnychi WWTP the sludge beds occupy an area of 272 ha, with more than 10 mln. m^3 of sewage sludge accumulated; in Lviv, the drying beds occupy an area of 22 ha, on which more than 1.6 mln. m^3 of sludge have been accumulated and 3,000 m^3 of fresh sludge are produced daily. Thus, there is an urgent need for reconstruction of WWTPs throughout in Ukraine.

The construction of new treatment unit #1 and the reconstruction of treatment units #2 and # 3 are planned at Bortnychi WWTP in Kyiv, which will provide full biological wastewater treatment using nitrification and denitrification zones in aeration tanks, as well as the construction of gravitational and mechanical sludge thickeners. The final product of the WWTP will be an ash, which can be used in the industry.

The construction of a biogas station is planned at Lviv WWTP. It will consist of digestion facilities for sludge from the primary clarifiers and excess activated sludge from the aeration tanks. Obtained biogas will be used to produce electricity and heat (Kizieiev et al., 2016).

A complete reconstruction of WWTP is planned in Kharkiv, with the subsequent construction of a biogas plant that will generate energy through the digestion of sewage sludge and will reduce the area of drying beds from 126 ha to 30 ha. The reconstruction of WWTP will allow using more rationally the waste generated as a result of wastewater treatment.

Due to the fact that in Ukraine only 3–5% of sewage sludge is used as secondary raw material, there is a need to find new and effective methods of its utilisation. To date, most non-disposal sewage sludge in Ukraine is used in agriculture as organic fertilisers. According to research data, the use of fertilisers based on sewage sludge improves the quality of soil, namely humus content is increased (Rudnytskiy, 2013). In current economic conditions of Ukraine, this method of sewage sludge utilisation is one of the most effective.

Taking into account the problems associated with the technical condition of WWTPs and the formation of large quantities of sludge, the key task is to clearly identify which method of utilisation would be most appropriate and cost-effective.

The main task of our research is to find the optimal, environmental friendly and cost-effective utilisation method for a large amount of old accumulated sludge, as well as of fresh sludge. Analysis of the previous studies, e.g., Shkvirko et al. (2019b), confirms that sewage sludge is a valuable material and energy resource that can be used as a secondary raw material. Ukraine should study the experience of other countries, where most of the formed sludge is used as secondary raw material. Thus, a promising way of sewage sludge utilisation in Ukraine is the production of growth substrates for the biological reclamation of waste dumps and quarries.

Since in Ukraine there is an increasing need for biological reclamation of landfills, spoil-heaps, etc. (Shkvirko et al., 2019a) and this process requires considerable resources and financial costs, it is extremely promising to find the ways to reduce its cost and conserve natural resources.

In this way, we will be able to simultaneously influence two extremely widespread environmental problems in Ukraine and offer an interesting technological solution for the use of nutrients from man-made wastes and for providing the process of biological reclamation. It is advisable to consider the use of encapsulated mineral fertilisers in biological reclamation technology (Nagurskyy et al., 2019).

4 Researches on the creation of growth substrate using sewage sludge

The subject of our study was the fresh sewage sludge obtained after wastewater biological treatment at Lviv WWTP (Figure 1).

The first step of investigations is to determine the properties of sewage sludge, its composition and the possibility of using in the growth substrate. The second step is to create a primitive substrate from a mixture of sewage sludge and ordinary soil, and to check the possibility of plant growing by means of bioindication. The third step is to improve the obtained substrate to ensure its basic functions and maximum content of recycled materials.

The qualitative indices of sewage sludge were determined according to usual procedures in the laboratory of agrochemical, toxicological and radiological studies of soil ecological safety and product quality of the Lviv Branch of the public institution 'Derggruntokhorona'. The main indices were: humidity, pH, organic matter content, basic biogenic elements (phosphorus, potassium, nitrogen), as well as trace elements and heavy metals.

Figure 1 Location of the sludge drying beds at Lviv WWTP (see online version for colours)

The obtained data show the presence of significant amounts of main biogenic elements in sewage sludge (N – 3.56%, P – 1.6%, K – 0.3%), macro- and microelements, as well as high content of organic matter (23.8%), which can provide plants with nutrients. The content of available forms of heavy metals in the samples did not exceed the maximum permissible values. The acidity of the medium should not have an inhibitory effect on plant growth and development.

Based on the results of our research, we can conclude that the chemical composition of the sewage sludge is relatively safe for its use as growth substrate. Thus, in this series of studies no systematic measurements of the content of hazardous contaminants in cultivated plants were performed. The main purpose was to test by the bioindication methods the suitability of different variants of growth mixtures based on the sewage sludge.

Bioindication was performed according to Ukrainian State Standards DSTU ISO 11269-1:2004 and 11269-2:2002. The growth substrate was compared to the check soil. Ordinary barley (*Hordeum vulgare*) and watercress (*Lepidium sativum*) were used for bioindication. This method is suitable for all soils, soil-based materials, wastes or chemicals that may be introduced into the soil. According to this method, the growth substrate is a mixture of test soil and check soil, which is known to have good quality. Two kinds of plants belonging to one of the categories were selected for the experiment.

- Category 1 – Monocotyledonous plants: rye, rice, oats, wheat, barley, common sorghum, corn.
- Category 2 – Dicotyledonous: mustard white, rapeseed, radish and wild turnip, Chinese cabbage, garden watercress, tomato, beans.

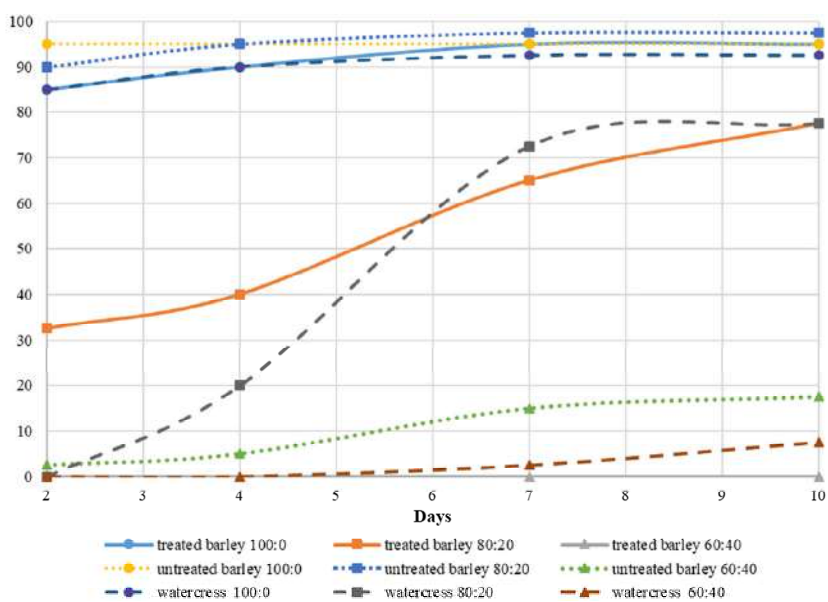
Before using each seed was analysed to determine their germination energy. Ten identical seeds of every plant were bedded into separate pots and the percentage of seed germination relative to the average germination in the check pots was calculated. The length of the longest root of each plant was measured and the average length was determined for each growth substrate. A statistical analysis was used to determine the least significant differences between the check and test samples.

The ratios of fresh sludge and typical dark-grey podzolic soil (in %): 100:0; 80:20; 60:40; 40:60; 20:80; 0:100. Bioindication was carried out in Petri dishes planting ten seeds of treated spring barley (Vitavaks 200 FF, germination 95–97%), untreated spring barley (germination 95–97%) and watercress (germination 92–95%). The experiments were performed in four replicates to ensure the reliability of the studies.

During the experiment, the following indicators were monitored: the time of germs appearance, number of new germs per day, the total germination. After the experiment the length and weight of the overground part, as well as the length and weight of roots were measured.

The results of bioindication are represented in Figure 2. When using experimental substrates with the sludge content of more than 40%, the plants did not germinate, so these results are not reflected.

Figure 2 Average germination of bioindicators in different growth substrates as function of time, % (see online version for colours)



After plant germination the influence of the substrates on the plant development was determined. The results of phenological observations and weight calculations of the grown plants-bioindicators on the tested substrates are presented in Table 1.

The results show that the acceptable amount of sewage sludge for the production of the growth substrate under such conditions is equal about 20%, because for all bioindicated plants the number of seedlings at the end of the experiment did not differ from the check sample value (treated barley – 17.5%, watercress – 15%), and for untreated barley even exceeded it (by 2.5%). However, it should be noted that during first seven days of investigations there was a delay in the plant germination (especially for watercress and treated barley) when using the investigated substrates.

The addition of sewage sludge in amount of 40% has a negative impact on all studied plants. For the treated barley no germination was observed; for the untreated barley and watercress it was 17.5% and 7.5%, respectively. Therefore, it should not be recommended to use such amount of sewage sludge for the growth substrate production.

The obtained results show that the total weight of plants does not change significantly (from +5.4% to –9.1%) when using the substrate with 20% of sludge. But the difference in length is more significant (aboveground part: from +9.0% to –30.5%, roots: from –19.9% to –57.1%).

When using 40% of sludge in the growth substrate, a much greater effect on plant growth and development was observed, namely: total plant weight ≈18.5%, height of the aboveground part: from –25.8% to –54.6%, roots: from –65.1% to –87.8%.

The results show that sewage sludge contains a significant proportion of nutrients and can be used in the mixture to produce growth substrate. Presence of 20% of fresh sewage sludge in the growth substrate does not influence the germination, growth and development of bioindicators; moreover, in some cases this impact is even positive.

Table 1 Changes in plants growth and development depending on substrate composition

	Average height of plant overground part, m	*Average length of plant underground part, m*	*Average weight of plant, g*	*Average weight of stem, g*	*Average weight of roots, g*
Treated barley					
Check sample	0.1083	0.1819	0.239	0.155	0.084
Substrate 1 (80:20)	0.0851	0.1112	0.252	0.147	0.105
Substrate 2 (60:40)	-	-	-	-	-
Ordinary barley					
Check sample	0.1176	0.1902	0.286	0.168	0.119
Substrate 1 (80:20)	0.1282	0.1524	0.260	0.165	0.095
Substrate 2 (60:40)	0.0873	0.0664	0.233	0.185	0.048
Watercress					
Check sample	0.0436	0.0531	0.0225	-	-
Substrate 1 (80:20)	0.0303	0.0228	0.0205	-	-
Substrate 2 (60:40)	0.0198	0.0065	-	-	-

Thus, sewage sludge can be used to produce growth substrate for the biological reclamation of disturbed lands, but it is necessary to select the appropriate composition.

The results showed that amount of sludge should be about 20%. However, in our opinion, if the substrate is provided with other components, for example sorbents, it will be possible to increase the content of sludge in the substrate.

Taking into account the results of previous studies and analysis of the literature data, it was decided to add natural sorbents to the substrate to reduce the negative impact of heavy metals on the plant. Sorbents have a large buffer capacity and ability to absorb contaminants, thus reducing their supply to the plant. Also, natural sorbents are a source of nutrients and substances that improve the physical condition of the soil. The fractional composition and density of the zeolites do not change significantly over time, allowing to use them for a long time.

The studies were performed with fresh sludge, which was added to the dark-grey podzolizic soil in amounts of 0, 20%, 25%, 30%, 35% and 40%. The amounts of sorbent added to the substrate were 0, 5%, 7.5% and 10%. The experiments were performed in triplicate to ensure the reliability of the studies. Bioindication was carried out in Petri dishes, planting ten seeds of spring barley in each of them (germination 95–97%).

During the experiment, the following indicators were monitored: the time of germs appearance, number of new germs per day, the total germination (Figure 3). After the experiment the length and weight of the overground part, as well as the length and weight of roots were measured.

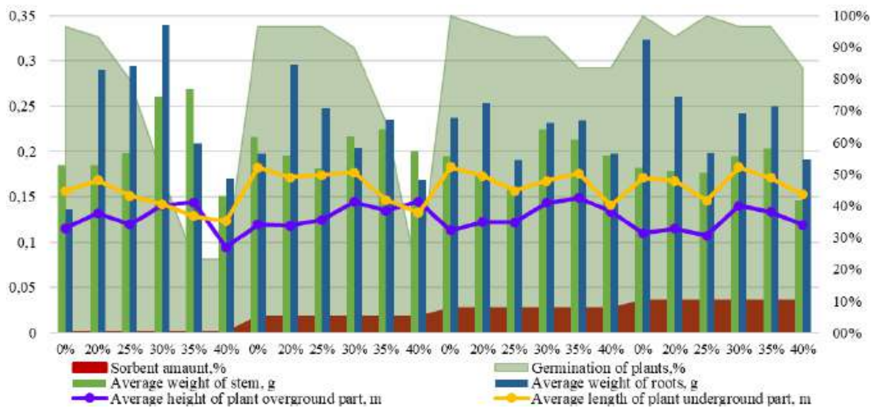
Figure 3 General view of bioindicators planted in the investigated substrates (see online version for colours)

According to the results of previous studies, a maximum of 40% of sludge was added to this substrate and ordinary barley (*Hordeum vulgare*) was used as a bioindicator.

The results of this stage of investigation are presented in Figure 4, the main parameters were recorded on the 10th day of the experiment.

The results show that for the substrates with 40% of sludge and without the sorbent the average germination was 23%; for the substrates with 40% of sludge and 7.5% of the sorbents the germination was 83.33%. For all substrates with sludge and sorbents, with the increase in sludge amount a better development of the aboveground part of the plant was observed. Thus, it is necessary to add the sorbents into the substrate composition, which would allow increasing the sewage sludge amount up to 40%, and possibly even more, without any harmful effect for the plants.

Figure 4 Development of bioindicators depending on substrate composition (see online version for colours)



After statistic processing of the obtained data using correlation analysis, we obtained the following results:

- the percentage amount of zeolites in the substrate directly correlates with root length (0.45) and plant germination (0.52)
- the percentage amount of sewage sludge directly correlates with the height of the aboveground part of the plant (0.49) and inversely correlates with root length (–0.54) and plant germination (–0.55)
- root length directly correlates with plant germination index (0.81).

Thus, the amount of added sludge mainly affects the growth and development of the aboveground part of the plant; the addition of sorbents significantly increases the percentage of germinated plants, and has a positive effect on the development of the root system.

5 Prospects of using the developed innovative technology for biological reclamation of disturbed lands and perspective directions of new researches

Prospects of using the developed innovative technology are estimated by predicting the improvement of the ecological state as result of the building of the technological line for the production of growth substrate on the basis of sewage sludge at Lviv WWTP. It should be noted that similar financial indicators and similar environmental and social effects can be achieved in the case of installing the analogous line at any WWTP of Ukraine, which are similar in structure and technical indicators.

At the beginning of 2019 the area of sludge drying beds at Lviv WWTP was equal about 22 ha. The area of the drying beds with improved concrete coverage is 6.0 ha, the remaining 16.0 ha are old soil-based drying beds. Taking into account the damp climate of Lviv, the overfilling of existing drying beds, and the lack of free space for their enlargement, sludge deposition on the drying beds is low-efficient and requires changing of the sludge utilisation method at Lviv WWTP.

Drying beds at Lviv WWTP have been in operation since 1964. During the years of operation about 1 million tons of sludge have been accumulated. Unpaved drying beds have almost completely exhausted their resources and are overfilled, whereas a part of the improved concrete beds has not yet been filled and they serve as the last reserve structures of Lviv WWTP for potential deposition of the sewage sludge.

The average flow rate of sewage sludge at Lviv sewage treatment plants is estimated as 3,000 m^3 per day with an average water content of 96%, which equals to 120 tonnes of sludge dry matter per day or 400 tonnes of mechanically dewatered sludge with a moisture content of 70%.

In our opinion, it would be promising to build a technological line to produce a growth substrate, based on sewage sludge of Lviv WWTP with a capacity of 150 tonnes per day on the basis of existing concrete sludge drying beds.

As a result of the project it is expected:

- economic efficiency due to the implementation of biocompost and obtaining of large land area within the Lviv city; this area may be used for the energy crops cultivation or for the construction of a solar power plant
- budgetary efficiency, including additional revenues to the local budget due to the biocompost production by the communal enterprise 'Lvivvodokanal'
- positive social impact (open drying beds are the source of unpleasant odours that periodically spread around the adjacent part of Lviv; implementation of the project will partially reduce the emission of harmful gases into the atmosphere and provide a mechanism for complete elimination of this negative factor in the next 10–15 years).

At the biocompost production cost of 217 UAH for 1 tonne and the sale of compost on the terms of self-transport at the price of 0.3 UAH/kg (about 5% of the market price of agricultural biocompost), the profitability of the sewage sludge composting technological line at Lviv WWTP will be equal 38%. With an average amount of biocompost of 150 tons per day the estimated profit is expected at the level of 12,450 UAH per day or 4.54 mln. UAH per year.

The implementation of a plant for the production of growth substrate at Lviv WWTP is especially relevant from an environmental point of view. Thus, overfilled drying beds located directly in the valley of the Poltva River pose an imminent threat of the surface and groundwater contamination and are a source of greenhouse gas emissions. The use of intensive processing and disposal methods of sewage sludge will potentially free up large areas of land which are not suitable for civil or industrial construction, but can be effectively used for the production of alternative energy, namely for the cultivation of energy crops or for the construction of a solar power plant. The large Lviv thermal power plant #2 located nearby drying beds (about 1.0 km) makes such energy development of these territories especially economic attractive. Construction of the anti-filtration screen between the old soil-based sludge drying beds and the Poltva River will reduce the potentially dangerous surface and ground water flows from the existing drying beds to the Poltva River in amount of approximately 50,000 m^3 per year, as well as will decrease the emission of greenhouse gases from the drying beds to the atmosphere in amount of about 10,000 tons annually.

The problem of production of the growth substrate for the purpose of afforestation of areas damaged by uncontrolled deforestation in the Carpathians needs separate solution. The resources of fertile soils in the Carpathians do not allow large-scale realisation of this afforestation. At the same time, wood waste is a major environmental pollution in the region. In our opinion (Masikevych et al., 2019), a promising way of preventing environmental pollution from this waste is to use it for biofuel production. A sulphate soap which is the lignin-containing waste of cellulose production is suggested to use as a binder. The smallest fraction of wood waste (wood dust) which is sifted from the dried raw material after the drying stage can be successfully used as an organic-containing component of the growth substrate, improving its structural characteristics. But new wide investigations should be done to determine the optimal composition of the growth substrate of this type.

To our mind, for the integrated applications of reclamation and afforestation it is rational to use mineral fertilisers of prolonged action in combination with the proposed substrate. The prolonged action of the fertiliser is achieved by encapsulation of traditional granular fertilisers with a water-permeable capsule (Moroz et al., 2019). The prerequisites for the production of such capsules are the environmental safety, specific physical and mechanical properties and the effectiveness of prolonged release of nutrients. We propose to use plastic waste as a part of the capsule-forming composition, which allows reducing the cost, as well as providing the appropriate physical and mechanical properties of the fertiliser. Encapsulation should be done in the fluidised bed apparatus using the industrial polymeric waste, which should be dissolved in the solvent. After the coating, the solvent is evaporated, providing the capsule with the required strength and integrity of the coating. Under the conditions of corresponding solvent availability a polyethylenterephthalate could be the component of the film-forming composition. The system of separate collection and recycling of this plastic is widely developed in Ukraine and other countries, but available solvents to provide technology for applying a polymer solution with the subsequent evaporation of this solvent and the creation of a water-permeable capsule around the fertiliser are absent. We have investigated the possibility of modifying polyethyleneterephthalate via alcoholises reaction using diethylene glycol as a reagent. As a result, the modified polyethylenterephthalate is dissolved in ethyl acetate and it is sufficient to realise the process of capsule formation in the fluidised bed apparatus. The resulting fertilisers of prolonged action are environmentally friendly because they prevent environmental contamination by undigested nutrients of plants and trees.

6 Conclusions

Man-made wastes such as sewage sludge after the wastewater biological treatment can be used as a component of a growth substrate but with definite limitations. In a large percentage amount no germination of bioindicators is observed, so the optimal suggested content of the sludge in growth substrate is about 20%. This result can be caused by many factors that affect plant growth and germination, inhibitor content and changes in basic agronomic parameters, because high-viscous fresh sludge contains a great amount of moisture (70–75%).

The addition of insignificant amount of natural sorbents (≈5–7.5%) to the growth substrate improves its structural properties and binds the moving compounds of hazardous substances. In such a case it is possible to increase the content of the sewage sludge in the substrate.

Ordinarily, the growth substrate needs to be improved relative to the component composition in such a way, that the amount of man-made waste would be the maximum, and the amount of fertile soil would be the minimum. However, even the substrate with the proposed composition will be able to reduce twice the amount of fertile soil for biological reclamation, as well as the cost of this process. And the most important conclusion is that the man-made waste can be reused to eliminate adverse environmental effects caused by human activities.

In our opinion, the results achieved on the creation of growth substrates of various types on the basis of sewage sludge and other organic-containing wastes show that they can be used to improve the ecological situation at the WWTPs. At the same time, the successful reclamation and remediation of landfills, waste dumps and quarries, as well as afforestation of the territories may be achieved.

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