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Development of Bioproductive Soil Mixtures Using Subway Construction Waste for The Purpose of Improving the Territory of The City

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***Abstract*: The article presents the results of research on the bioproductivity of ecologically clean waste generated during excavation work on subway construction sites and other underground construction. It is proposed to use waste as one of the components of soil mixture preparation. In the course of the work, soil mixtures varied in relation to the waste/peat soil. A number of laboratory experiments on the germination of a lawn grass mixture, widely used in the improvement of cities, was set up. Based on the results of the work, recommendations were proposed for compiling a methodology for studying artificial soil mixtures.**

***Index Terms*: landfill; peat soil; ryegrass; solid waste; subway.**

I. INTRODUCTION

The construction of new subway stations and other underground construction is inevitably accompanied by the formation of a large amount of waste represented by rock extracted from the underground workings. When transporting waste, the load on the roadway increases, the air is polluted with the exhaust gases of the dump trucks, some of the waste can wake up on the road surface, the use of dump trucks increases the load on the roadway, the disposal of waste at landfills harms the environment, enterprises pay a fee for transportation and placement of breaths [1]. The presented article deals with solid wastes generated during the construction of Saint-Petersburg metro stations.

According to engineering and environmental surveys and conducted environmental monitoring, the waste is not contaminated with dangerous substances and corresponds to the fifth class of danger. The waste (potential soil) formed during excavation works is mainly represented by clays (up to 50%) and loams (up to 30%), and sands (up to 20%). Nevertheless, studies conducted by experts of the University of Mines with the use of innovative monitoring tools show that in the areas where waste is located there is an unfavorable dusty environment [2-6]. The resulting waste (potential soil), as far as education is transferred to third-party organizations for placement on landfills. The landfills are located at a relatively large distance from the waste generation areas, the haulage of trucks is more than 50 km [7-8]. There are many directions for the application of clay, such as: the production of building materials, refractory materials, ceramic products, the production of drilling fluids, use as a sorbent [9], and also, the preparation of soil mixture [10-11]. The scientific novelty consists in proposing a new method for recycling waste – a potential soil that forms during the construction of underground facilities during the construction of subway facilities through its reuse, as the main component of the soil mixture. The development of the method was carried out on the basis of data on the fertility of various soil mixtures prepared using this waste. The method assumes the receipt and use of a soil mixture for the purpose of improving the city. The problem of countering the erosion of unreclamated surfaces of urban and industrial facilities is now extremely relevant, as evidenced by numerous studies of specialists in this field [12-17]. In turn, the consequence of weathering and leaching of pollutants by precipitation from the uncultivated territories of the city is secondary pollution of surface water bodies, for example, in Saint-Petersburg there was a significant deterioration in the condition of the Murinsky Creek [18].

II. PROPOSED METHODOLOGY

A. General description

The chemical composition of the samples was studied using XRF-1800 Shimadzu wave X-ray fluorescence spectrometer.

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The study of the applicability of the waste to prepare the soil mixture was carried out on the basis of experiments on the germination of the test culture. As a test culture, a lawn grass mixture of the following composition was chosen:

1) Long-term ryegrass "Henrietta", 30%;
2) Long-term ryegrass "Romeo", 30%;
3) Long-term ryegrass "Fancy", 30%;
4) Long-term ryegrass "Roadrunner", 10%.

This grass mixture is often used in the greening of urban lawns in Saint-Petersburg. Ryegrass tolerates temperatures well below minus 15 °C without snow cover, does not require frequent irrigation and additional fertilizers. Life expectancy is 3-5 years.

To fix the growth of plants, a stand was mounted, with a drawn horizontal line at the level of the upper boundary of the soil and two rulers. The results of observations are recorded by photographing and recording of visual changes. Photo fixation is made against the background of the stand in a horizontal view for each for each sample analyzed individually, for a series of waste/ peat soil mixtures in comparison with 100 percent peat soil (as a control sample).

B. Algorithm

The waste is studied as a component of the soil mixture, which can be used to solve the problems arising in the city and the immediate area, such as:

- creation of a soil-vegetative layer (SVL) in the territories disturbed by construction [19];
- restoration of SVL on disturbed and polluted landscapes [20];
- increase in the power of the SVL, for example, in low-lying, flooded zones;
- subsidence of soil during the reorganization of the SVL [21];
- creation of SVL in alluvial landscapes [22-24];
- reclamation of disturbed and polluted areas (for example, waste landfills) or areas with high salinity soil [25].

The paper considers the use of soil mixture for the purposes of improvement. The general scheme of the proposed method of utilization is shown in Figure 1.

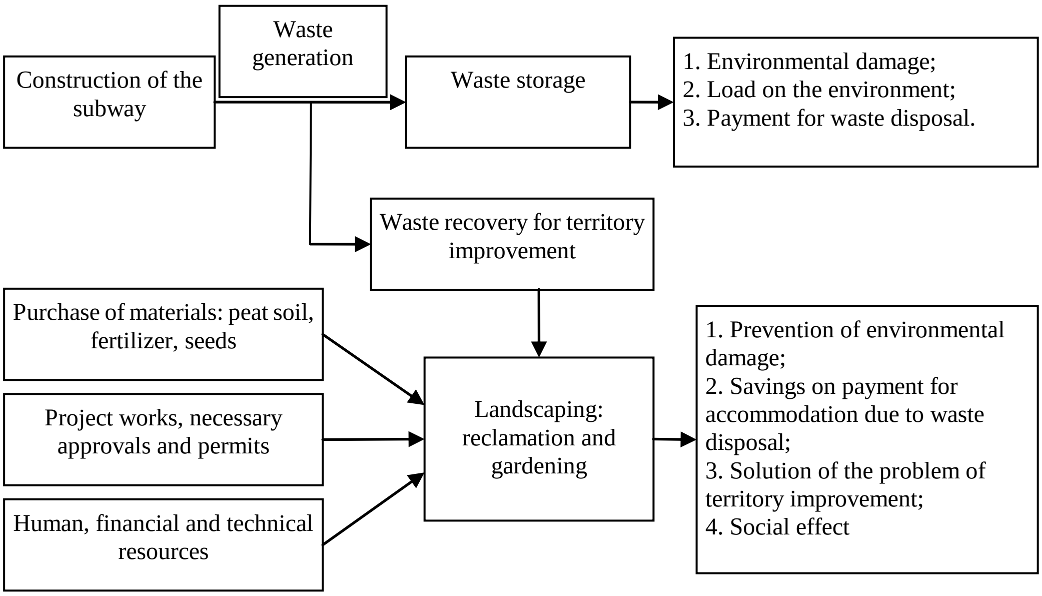


Fig. 1: Scheme of the proposed method of waste disposal

As a result of utilization of waste, the proposed method produces a soil mixture intended, first of all, for the needs of the garden and park economy. Such soils are used to grow lawn grass, shrubs and trees. In addition to the fact that the resulting soil mixture must comply with the safety indices and requirements for vegetation, it should ensure the growth of green plantations no worse than the well-known widely used soils. This requirement refers to the fertility of the soil of certain ecological zones [26-28].

Various kinds of soils [29] can be added to the waste, but for the northern regions, the most relevant is the use of peat soil. The possibility of using peat as a basis for plant growth is also confirmed by scientific research [30-35]. The efficiency of utilization is increased by increasing the amount of waste in the soil mixture, provided that the fertility requirement is met.

To assess the fertility of the soil mixture of different compositions, the authors put an experiment, the goal of which is to establish the optimal ratio of waste/peat soil. The optimal ratio is determined by the indicators of germination, growth, health, survival, color of the test culture being sown.

The herbal mixture used is often used in the greening of city lawns in Saint-Petersburg. Ryegrass tolerates temperatures well below minus 15 °C without snow cover, does not require frequent irrigation and additional fertilizers. Lifetime is 3-5 years [36].

Waste sampling was carried out from temporary storage sites in the territories of four construction sites of new Saint-Petersburg metro stations (Figure 2).

The chemical composition of the samples was studied using a XRF-1800 Shimadzu wave X-ray fluorescence spectrometer. The results of the studies are presented in Table 1.

Clay waste was mixed in various proportions with a peat-sand mixture. The peat-sand mixture had the following composition: peat of the lower and upper 60%, sand - 40%. In the peat-sand mix, mineral fertilizers were additionally added in the following ratio: N - 350 mg/kg, P2O5 - 400 mg kg, K2O - 500 mg/kg.

Fig. 2: The layout of the construction sites of the subway

As a result of the literature review, the author has established that the soil mixture can contain up to 80% of physical clay in its composition [37-38]. At present, a method for producing a peat-based soil mixture is known (Patent # 2067969 of the Russian Federation) [39]. The known method assumes the use of clay as one of the main components of the soil mixture (up to 30% of the total volume). The soil mixture obtained by this method is intended for agricultural purposes. A disadvantage of the known method is that the composition of the soil mixture has not been specially adapted for the use of the resulting soil in urban areas.

Based on the results of the literature review and patent search, it was decided for the first series of experiments to apply the following waste/peat soil ratio as a percentage by mass: 80/20, 60/40, 50/50, 40/60, 20/80, and as a control a 100% peat soil was used.

As containers for planting, plastic containers with a volume of 500 ml, 10 cm in height were chosen. The waste and peat soil were mixed with a spatula to a relatively homogeneous state. At the bottom of the container was laid drainage (expanded clay), a layer 1-1.5 cm thick.

Table 1: Content of chemical elements in the tested waste (%)

Substance	**Construction sites**			
	1	**2**	**3**	**4**
SiO_2	62,03	62,71	71,20	61,86
Al_2O_3	19,93	15,57	12,58	19,01
K_2O	4,82	4,05	3,78	4,71
Fe_2O_3	6,39	6,74	3,46	7,30
CaO	0,20	3,20	2,30	0,67
MgO	1,69	2,06	1,13	1,70
TiO_2	1,13	0,95	0,70	1,13
Na_2O	0,08	0,73	0,66	0,14
SO_3	0,08	0,16	0,53	0,17
P_2O_5	0,05	0,26	0,25	0,12
BaO	0,12	0,15	0,16	0,14
Cr_2O_3	0,05	0,07	0,08	0,04
MnO	0,03	0,12	0,07	0,11
Nd_2O_3	0,00	0,03	0,00	0,00
ZrO_2	0,02	0,02	0,03	0,02
SrO	0,01	0,03	0,03	0,01
Cl	0,00	0,02	0,02	0,00
Ga_2O_3	0,00	0,02	0,00	0,00
ZnO	0,02	0,01	0,01	0,02
Rb_2O	0,01	0,01	0,01	0,01
Co_2O_3	0,00	0,00	0,00	0,00
NiO	0,01	0,01	0,00	0,01
CuO	0,00	0,01	0,00	0,00
C	1,22	0,73	1,26	0,73
Moisture	2,11	2,34	1,75	2,12

For planting were selected seeds of Ryegrass perennial in an amount of 400 pcs. (Figure 3).

For this purpose, 400 pieces were selected. seeds, after which they weighed. Then, the required number of samples of seeds with a reference mass m = 1.16 g was selected. When planting, the seeds were evenly spilled onto the soil surface and mixed with the top layer. After planting, the soil was moistened with a spray gun. Watering is carried out with tap water at room temperature.

Containers with sown grass are placed on the windowsill. The average daily temperature near the window is 12 °C, and at the edge of the sill on the side of the room is 18 °C. Lighting in the first stage is natural, coming through the window.

To average the growth conditions of all test objects, the containers are sorted in the reverse order every day. Watering in the first stage is carried out daily, 50 ml of water is poured into the container by means of an atomizer. To fix observations, a stand was mounted, with a drawn horizontal line at the level of the upper boundary of the soil and two rulers. The zeros of the rulers coincide with the horizontal line.

Fig. 3: Photo of the used grass seed mixture

The results of observations are recorded by photographing and recording of visual changes. Photo fixation is made against the background of the stand in a horizontal view for each container individually, for a series of 5 blends and a control sample of each source of waste, for 4 samples of each source of waste the same mixing with the control. Also, for a visual assessment of health, density and coloring of the shoots, a photo fixation is made against the background of the stand in the 45-degree view.

Each container is marked for identification. Planting of seeds was carried out on 28 November 2017. The results of plant growth measurements are shown in Table 2.

Table 2: The results of measurements of plant growth in test mixtures of waste/peat soil

Measurement date	**The construction site from which the waste used in the test mixture was selected**	**Average height values of germs (cm) at different weight ratios of waste/peat soil**					
		80/20	**60/40**	**50/50**	**40/80**	**20/80**	**Control sample 0/100**
03 December 2017	1	2,0	1,5	2,0	2,0	2,0	2,0
	2	1,5	2,0	2,0	1,5	1,5	
	3	2,0	2,0	2,5	2,5	2,5	
	4	2,0	2,0	2,5	2,5	2,5	
06 December 2017	1	5,5	4,5	5,5	6,5	4,5	6,5
	2	5,5	4,5	5,5	5,5	5,0	
	3	5,5	5,5	5,5	5,5	5,5	
	4	6,5	4,5	5,5	6,5	4,5	
09 December 2017	1	8,5	9,5	9,5	9,5	10	11
	2	9	10	10	10	10	
	3	9,5	9,5	10	10	10,5	
	4	9,5	10	10	10	10,5	
12 December 2017	1	10,5	10,5	10,5	10,5	10,5	12
	2	11,5	12,0	11,5	11,5	11,5	
	3	11,5	11,5	11,5	11,5	11,5	
	4	12	12	12	12	12	
15 December 2017	1	2,0	2,0	2,0	2,0	2,0	2,0
	2	2,0	2,0	2,0	2,0	2,0	
	3	2,0	2,0	2,0	2,0	2,0	
	4	2,0	2,0	2,0	2,0	2,0	
18 December 2017	1	4,0	4,0	4,0	4,0	4,0	4,0
	2	4,0	4,0	4,0	4,0	4,0	
	3	4,0	4,0	4,0	4,0	4,0	

	4	4,0	4,0	4,0	4,0	4,0	
24 December 2017	1	4,5	4,5	4,5	5,0	5,0	5,0
	2	5,0	5,0	5,0	4,5	5,0	
	3	5,0	5,0	5,0	5,0	5,0	
	4	5,0	5,0	5,0	5,0	4,5	
31 December 2017	1	5,0	5,5	5,5	5,5	6,0	6,5
	2	6,5	6,5	6,0	6,0	6,5	
	3	6,5	6,5	6,0	6,0	6,5	
	4	6,5	6,5	6,0	5,5	5,5	
07 January 2018	1	6,0	6,0	6,0	6,0	6,5	6,5
	2	6,5	6,5	6,5	6,5	7,0	
	3	7,0	6,5	7,0	7,0	6,5	
	4	7,0	6,5	6,5	6,0	6,0	
14 January 2018	1	7,0	6,5	6,5	6,5	6,5	6,5
	2	7,5	7,0	7,0	7,0	7,5	
	3	7,0	7,0	7,0	7,0	7,0	
	4	7,0	7,0	6,5	6,5	6,5	
20 January 2018	1	9,0	8,0	8,5	8,5	8,5	8,0
	2	9,0	8,0	8,0	8,0	8,0	
	3	8,0	8,0	8,5	8,5	8,0	
	4	7,5	8,0	7,5	7,5	7,0	
26 January 2018	1	9,0	8,0	9,0	9,0	9,0	9,5

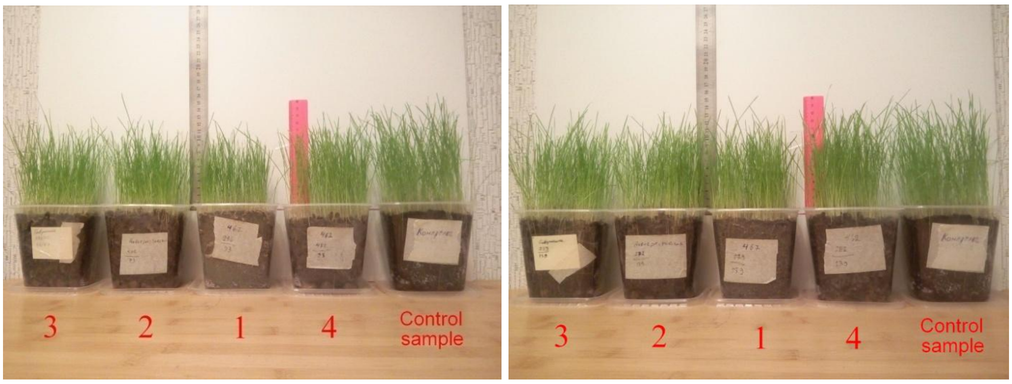
III. RESULT ANALYSIS

01 December 2017. In all the containers seeds of seedlings appeared in approximately the same quantities.

03 December 2017. Most of the seeds have risen. Seedlings had a healthy appearance and approximately the same height in all containers. A slight difference is most likely due to the difference in temperature and illumination at the window and on the side of the room.

06 December 2017. Growth in all containers is almost uniform. The color is the same. Germs have a healthy appearance and structure. The differences between the control samples and the subjects were not revealed. A photograph of the samples (06 December 2017) is shown in Figure 4.

Fig. 4: Photographs of samples (06 December 2017)



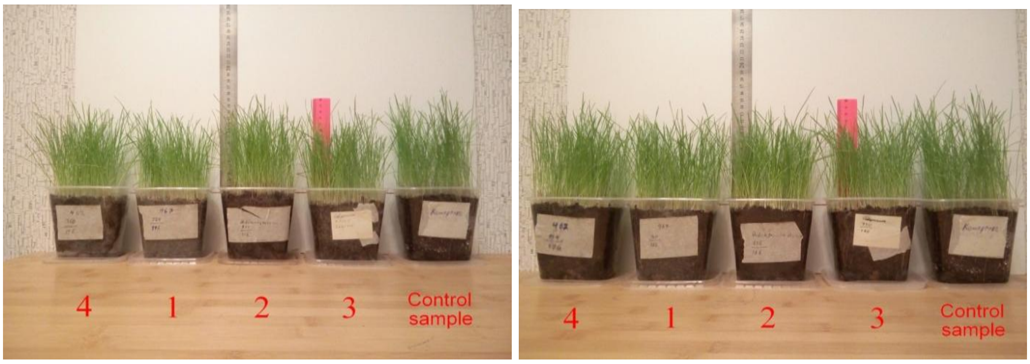
(a) (b)

Fig. 5: Photographs of a group of samples (09.12.2017): (a) - 80/20, (b) - 20/80

09 December 2017. Slightly behind in growth in the mixtures prepared from waste from construction site 1 in relation to control and other groups. A photograph of the sample group 80/20 (09 December 2017) is shown in Figure 5a. A photograph of the sample group 20/80 (09 December 2017) is shown in Figure 5b.

12 December 2017. Slight advance in the growth of a group of samples from the waste from construction site 4, but with equality with the control sample. Slight retardation in the growth of a group of samples from the waste from construction site 1 in comparison with the

control sample and other groups. A photograph of the sample group 80/20 (12 December 2017) is shown in Figure 6a. A photograph of the sample group 20/80 (12 December 2017) is shown in Figure 6b.

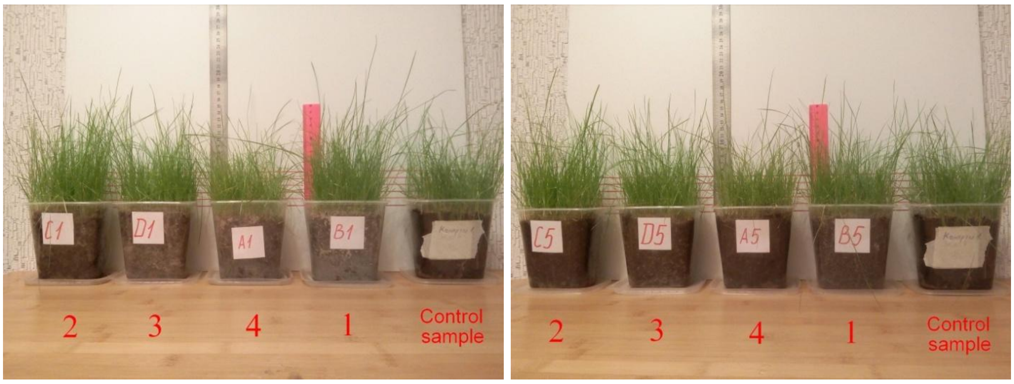


(a) (b)

Fig. 6: Photos of the sample group (12 December 2017): (a) - 80/20, (b) - 20/80

15 December 2017. The grass reached the critical growth rate for the experiment under given conditions. Bars began to bend and break when moving containers, the process of photographic fixation was difficult. Therefore, it was decided to shear grass in all containers under one level 2 cm from the edge of the container. To accelerate the growth rate of test objects over plants, a lamp with red and blue LEDs was installed. The lamp complements the natural lighting and works 10 hours a day. Further observations also include photo fixation of growth rates and a visual assessment of the morphological features of plants.

18 December 2017. The growth rate after cutting is somewhat slowed. So, for example, for three days, during the period from 06 December 2017 to 09 December 2017, test objects grew on average by 4-5 cm, and in the period from 15 December 2017 to 18 December 2017, the plants in all containers increased by 2.0 see Apparently, the delay is associated with a violation of the upper part of the structure of the leaves when cutting. The individual leaves grew to the mark of 9-10 cm, these were not cut off by the haircut, which sprouted after the main mass. The structure of leaves in all containers is the same, chlorosis and necrosis are not noted. Color - light green in all containers A photograph of the sample group 80/20 (18 December 2017) is shown in Figure 7a. A photograph of the sample group 20/80 (18 December 2017) is shown in Figure 7b.



(a) (b)

Fig. 7. Photographs of a group of samples (18 December 2017): (a) - 80/20, (b) - 20/80

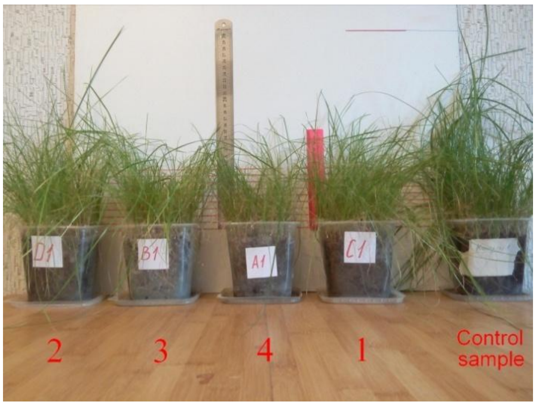
Six inspections of plants were carried out from 18 December 2017 to 26 December 2018. Height was also recorded and the state of plants was visually assessed. After cutting, the bulk of the shortened shoots reduced the growth rate compared to the previous period. The new, not trimmed sprouts that have outgrown the growth of a trimmed mass a few centimeters have risen and rapidly grown. This effect is clearly visible on photographs and is expressed in the visible interface of a thicker zone of the bulk of the leaves and a more thinned mass of unstripped shoots. Height measurements were made at the upper boundary of the main mass. Subsequently, the total mass of greenery became relatively homogeneous, and the height was measured at the lower boundary of the upper quarter of the total green mass. The containers were moved in the reverse order every week. The total growth rates for all variants of soil mixture ratios are the same and have a single trend. Insignificant fluctuations, most likely, are caused by insignificant differences in exposure conditions (illumination, temperature, air velocity).

Nevertheless, samples of 80/20 (construction site 1, construction site 4) and 60/40 (construction site 1) in the period from 16 January 2018 began to show slight signs of wilting. The reasons for this have yet to be clarified. There are suggestions that this is due to the structure of the soil mixture, the method of preparation which was different from the other groups.

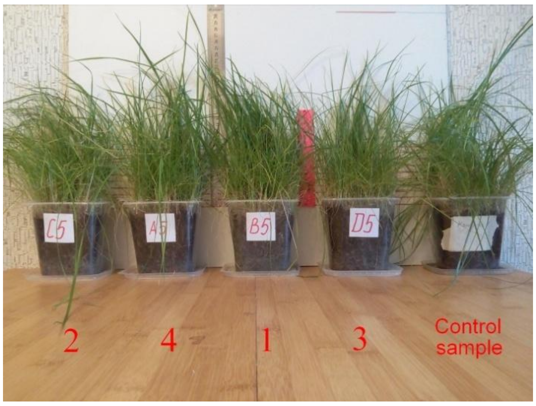
An excessively compacted soil mixture prevents moisture and air from reaching the plant roots, thereby inhibiting their vital functions. Since the amount of water for irrigation is approximately the same for all samples, and the soil structure is different, the amount of water supplied to the roots may be different. Such assumptions are confirmed by the fact that after watering the signs of withering of these samples noticeably weaken and the plants return to their normal state.

A photograph of the sample group 80/20 (26 January 2018) is shown in Figure 8a. A photograph of the sample group 20/80 (26 January 2018) is shown in Figure 8b.

Graphical representation of the growth rates of plants in the test soil mixtures is presented in Figures 9, 10, 11 and 12.



(a)



(b)

Fig. 8. Photographs of the sample group (26 January 2018): (a) - 80/20, (b) - 20/80

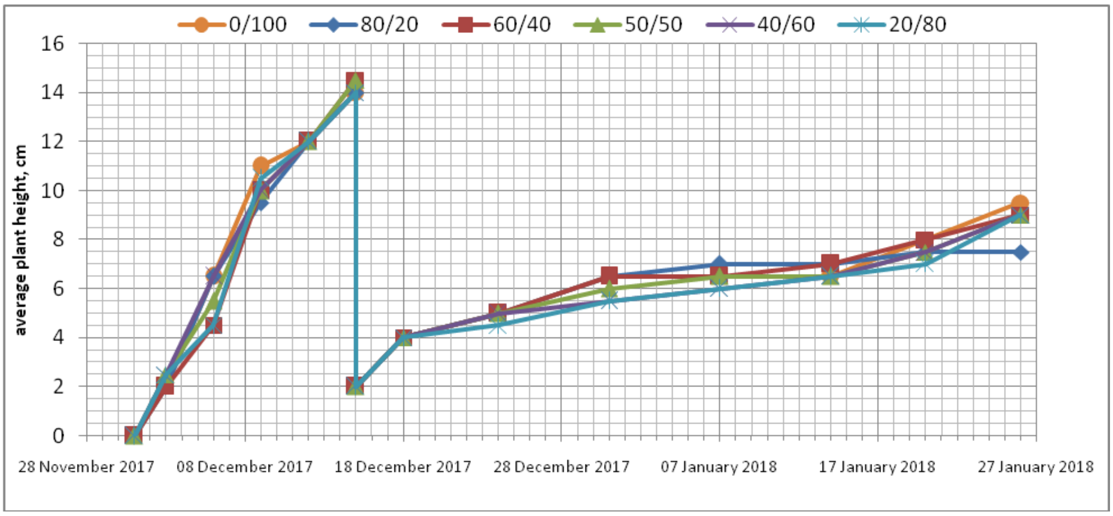


Fig. 9. Graphical display of plant growth rates in test soil mixtures prepared using waste from construction site

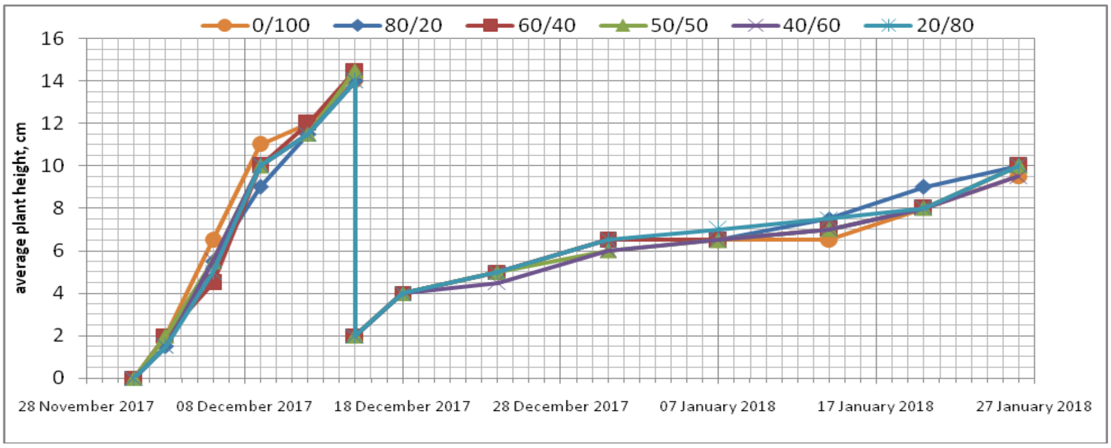


Fig. 10. Graphical display of plant growth rates in test soil mixtures prepared using waste from construction site

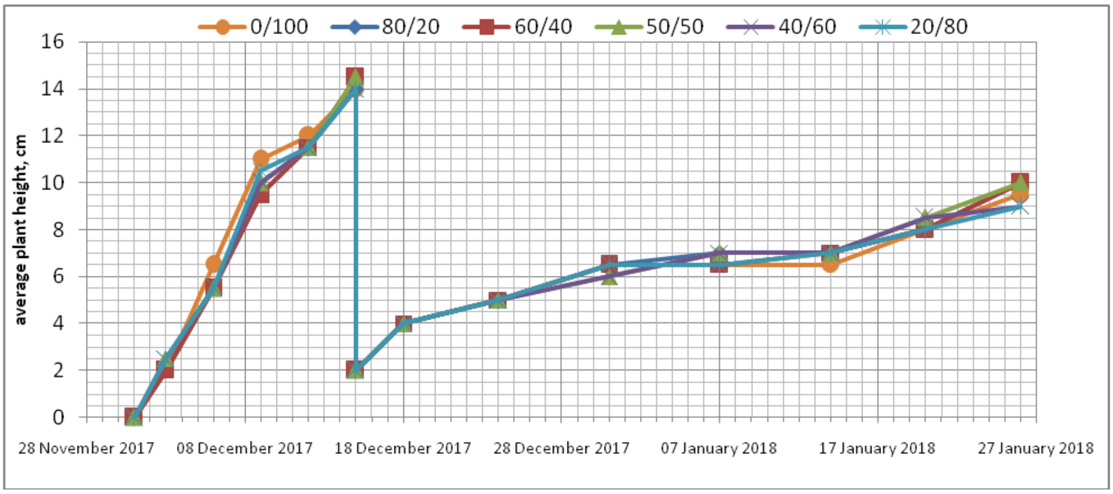


Fig. 11. Graphical display of plant growth rates in test soil mixtures prepared using waste from construction site 3

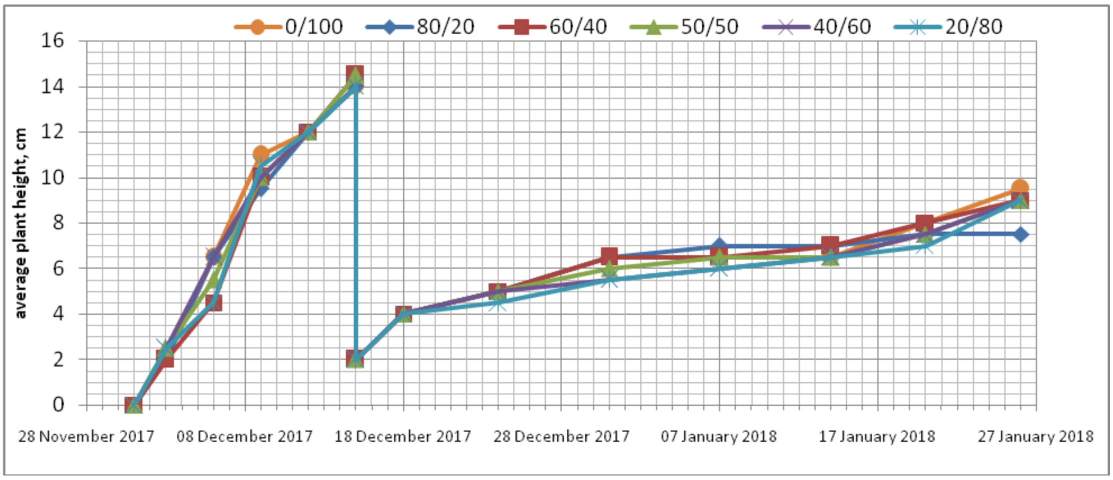


Fig. 12. Graphical display of plant growth rates in test soil mixtures prepared using waste from construction site 4

IV. DISCUSSION

The carried-out researches allow to draw a conclusion about admissibility of use of a ground formed as a result of underground construction with a view of an accomplishment, it is confirmed by other research [12, 40-41].

In the course of the work, soil mixtures consisting of waste (soil) and finished soil with applied mineral fertilizers and having different proportions of constituent components were obtained. The resulting soil mixtures were seeded with a gas mixture, placed in certain conditions, and further observations were made of the growth and condition of the plants during the entire exposure time. Alternatively, the waste (soil) can be mixed with enzymatic additives [42] or the use of construction and demolition waste [43] in order to improve the quality of the waste, thereby improving the economic importance of the waste as building material.

The experiment demonstrated the suitability of the resulting soil mixtures for use as a growth medium for lawn grass used in urban landscaping, road construction and embankment [44]. There is practically no correlation between the waste/peat soil ratio in the resulting soil mixture and the qualitative parameters of plant growth [32]. The qualitative parameters of plant growth include the rate of their growth, density, height of the leaves, the state of the structure, and the color of the leaves. Minor deviations are more likely due to the lack of ready-made technology for carrying out the experiment. Some mixtures turned out to be finely dispersed, as a result of which clay and peat particles coalesced upon contact with water and formed over-compacted soil blocks. Such blocks relatively poorly pass water used for irrigation, air coming from the surface and, as a result, create a less favorable environment for the development of the root system of plants [45]. In the natural conditions to the shortcomings of such a soil system, the hindered existence of soil inhabitants will be added: worms, insects and other soil inhabitants, which provide the necessary balance.

Other mixtures, on the contrary, turned out to be large cloddy. In such systems, the dimensions of the compacted blocks are smaller (up to 2 cm in diameter). In general, such systems are more favorable for the development of plants, inasmuch as access to moisture and air and, as a result, nutrition of the root system is better than in the case of a fine-dispersed system.

Proceeding from the described, watering such soil mixtures according to one principle, in the end, gave different results. The amount of water poured into each container was the same (about 50 ml), but the amount of water that reached the root system was different due to the different filtering capacities of the soil mixtures.

Illuminance of plants was also different. Although constant rotation of the containers under the lighting device was present, the quality of growth depended on the light conditions to a small extent.

Also, the quality of growth was influenced by a factor such as temperature, which fluctuations reached 5°C depending on the location of the containers. The temperature factor was leveled by the rotation of the containers. The factor of different air flow velocity, caused by ventilation of premises, including, could have an insignificant role in the development and growth of plants.

Of course, the recording and monitoring of these conditions affects the accuracy of the results. Nevertheless, the influence of these factors is insignificant in the light of practically identical results for all variants of soil mixtures. At this stage of the research, it is sufficient to prove the possibility of using waste as the main component of the soil mixture in the absence of a pronounced negative effect on the growth and development of planted plants [46]. This was proved for the mixtures obtained with a waste amount of 20 to 80%. There is an assumption that with an increase in the content of waste in the soil mixture, a negative effect on plants will appear in the form of a lag in the growth and quality of the leaves in relation to the mixtures already studied. To establish the lower limit of the negative effect, it is necessary to conduct an additional experiment, taking into account the experience gained, excluding the errors and errors admitted, which in passing will contribute to the development of the experimental procedure.

The methods for selecting the raw materials, the composition of the soil mixture, and the material for planting should be described. Unified and detailed method of mixing components, ensuring the reliability of the experiment. The methods of planting, watering, lighting, microclimatic conditions are regulated. The ways of fixing various parameters of growth and state, keeping records taking into account time intervals are described. The exposure time is determined, a method of processing the obtained results and their interpretation is proposed. The development of such a methodology will be based on already obtained results, in-depth analysis of the specialized literature and further research and experiments.

V. CONCLUSION

Such a technique can solve several problems:

1. Determination of the ecological frequency of the soil mixture;

2. Determination of the threshold for the onset of a negative effect;

3. Selection of the optimal composition of soil mixture for certain groups of plants.

Solving such problems will improve the quality of human-created fabricated landscapes; increase the economic and environmental effect of environmental protection measures. The eco-friendly approach used here is better than the use of nonbiodegradable materials such as waste tires or automobile tires [47-48] and steel slag from ironworks [49].

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