

# Utilization of industrial production waste as a component of the artificial soil mix composition

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**Abstract.** The technological development of mankind is accompanied with extracting a large amount of natural resources, which are then returned to the environment in the form of production and consumption waste. The problem of organizing industrial waste recycling is of high priority nowadays for all countries of the world, including the Russian Federation, due to the necessity to reduce the amounts of waste dumping at landfills. It is determined that 89 % of the waste, generated in the Belgorod region, result from the mining and metals sector and chemical industry. At present about 11 % of land resources in the world are disturbed lands, which require recultivation processes. As an alternative solution the application of artificial soil mixes on the basis of industrial waste is possible. It is demonstrated that the designed multicomponent compositions of artificial soil mixes with the use of industrial waste have no phytotoxic action on the development of higher plants, and can form a nutrient-rich fertile soil mix, which would provide the proceeding of physical-chemical processes between all its components, which increases the crop yield of higher plants – through the example of garden cress – by 20–40 % in comparison with the control sample. The designed soil mixes can be used when implementing the biological stage of recultivating technologically disturbed lands.

## 1 Introduction

The technological development of mankind is accompanied with extracting a large amount of natural resources, which are then returned to the environment in the form of production and consumption waste. The production waste includes various kinds of materials and substances, generated in manufacturing cycles or when developing technologies for manufacturing this or that product. Consumption waste includes all types of waste products, which have lost their consumer properties.

The problem of organizing industrial waste recycling is of high priority nowadays for all countries of the world, including the Russian Federation, due to the necessity to reduce the amounts of waste dumping at landfills for a number of reasons: lack of land areas, transportation costs, environmental hazards, loss of valuable components and many others.

The industrial production growth causes an excessive anthropogenic impact on the natural landscape. The technological processes in many branches of industry, including mining and processing industries, are associated with consuming a great amount of mineral resources and generation of large amounts of various waste products, which are dumped for permanent storage or burial in the natural environment. For this purpose tailing dumps, sludge depositories and landfills are used, which require large areas of lands, including lands suitable for agricultural use.

89 % of the waste, generated in the Belgorod region, are generated by the mining and metals sector and chemical industry. Thus, on the territory of the Lebedinsky mining and processing plant of the Belgorod region there is a tailing dump for the waste of iron-ore concentration by the wet magnetic separation process (WMSW), currently containing 1120 mln m<sup>3</sup> of it, the capacity of which will run out by 2027. In the north-east part of Belgorod there is a sludge depository for citric acid production waste, where 300 thousand tons of citrogypsum are stored. The industrial recycling of such waste products, which would take into account the requirements of ecology, resource-saving and economics and would integrally solve the issues of waste neutralization, management and recycling, is a comprehensive way of solving the current problem of accumulated waste.

Nowadays about 11 % of land resources in the world are disturbed lands, 60 % of them are in poor or very poor state [1]. The total area of the disturbed lands in the Russian Federation is about 1.5 mln ha, and in the Belgorod region by January 1, 2019, it made up 6.5 thousand ha. The formation of technologically disturbed lands in the region mostly results from opencut mining of mineral deposits or from carrying out geological exploration works [2]. On the territory of the region there are 328 quarries, including 84 depleted ones; in some of them sand and clay are still excavated by contracting entities, and at depleted abandoned deposits the garbage dumps were made [3].

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Therefore, there is a necessity of restoration of lands, disturbed by this or that influence of industrial production, and of including them again into the sustainable economic turnover, at the same time minimizing and eliminating the adverse impact on the environment.

The necessity of carrying out remediation works at disturbed lands is determined by the national standard of the Russian Federation “59057-2020 Environmental protection. Soils. General requirements for recultivation of disturbed soils”. Recultivation and amelioration of the disturbed soils allows keeping the proper quality of soil covering parameters, moderating the fluctuations of weather and climate conditions and improving the sustainability of agriculture [4]. Remediation works provide the quick integration of disturbed soils into the natural environment [5]. The problem of selecting the most efficient implementation method when recultivating disturbed lands is particularly topical.

Nowadays, for eliminating the adverse impact on the environment and for long-term storage of large-volume waste products, which find no application, the special comprehensive technological solutions, aimed at remediation of technologically disturbed lands, are applied, which can provide the ecological-economical effect at low material costs.

Recently, when carrying out recultivation processes, the lack of proper soils for creating the land’s surface and creating conditions for subsequent plants growing is observed. The currently used soils are characterized with a low content of biogenic elements and, first of all, of the humic substance.

The so-called artificial soil mix can be used as an alternative solution; this mix is a mixture of components, resembling the soil in its structure, but different in its composition. At the same time the artificial soil contains all the components, necessary for the development of plants and microbiota.

For designing artificial soil mixes, such mineral materials are used as sand, clay, gravel, break-stone, ash, crushed concrete, expanded-clay aggregate, zeolites, ground limestone, dolomite powder, old plaster and mineral fertilizers [7–9]. As an organic or organo-mineral constituent, peat, manure, compost, straw, leaf and branch shedding, sludge from sewage treatment

plants’ sludge ponds, household waste, tree bark, forest leaf litter, sapropel, sawdust etc. are used [10–13].

In artificial soils compositions some other components can be used, for example, water-retaining materials – non-toxic water-soluble gel-forming polymer from polyacrylamide class [14], synthetic materials, which provide the formation of small-volume substrates [15, 16], etc.

In artificial soil mixes, in a similar way as in the natural soil, the natural environment for growing virtually any plants can be created. This technology can be used not only at recultivation stages of, for example, borrow cuts, but also at the biological stage of restoring soil-formation processes in disturbed lands, to improve the fertility of lean soils, the self-purification capacity of soils and biocenosis reproduction.

It should be noted that it is possible to design compositions, which would be optimal for certain types of plant crops. An artificial soil mix is similar to natural ones, but is characterized with much higher quality and ecological cleanness. So, searching for new efficient variants of ground soils substitution and expanding the range of artificial soil mixes with high fertility indices are a relevant science and technology objective.

## 2 Materials and methods

The purpose of this work is designing the compositions of artificial soil mixes with the use of industrial production waste, which would be useful for recultivation works at technologically disturbed lands.

As a basis for designing artificial soil mixes samples the technical specifications for nutrient-rich soils production were taken. The analyzed samples of soil mixes were researched by the air-oven method, spectrophotometric, potentiometric, titration-based and conductometric methods.

## 3 Results and discussion

For the research the materials were used, conveniently divided into mineral and organic. As a mineral constituent, clay, vermiculite, citrogypsum, wet magnetic separation waste of ferruginous quartzites and sand were used (Tab. 1).

**Table 1.** Chemical composition of mineral components, wt. %

Component	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	R <sub>2</sub> O	SO <sub>3</sub>
Clay	45–66	14–23	0.5–1.6	3.0–5.0	1.0–2.0	0.1–0.5	2.5–4.0	–
Sand	75–94	2–2.4	–	0.6–0.8	0.5–2.0	up to 0.4	–	–
Vermiculite	38–49	12–17.5	up to 1.5	5.4–9.3	0.7–1.5	20.0–23.5	up to 0.8	–
WMSW	65–75	2–3	0.1–0.2	Fe <sub>gen</sub> 10–15	2–4	4.5–5.0	1.1–1.4	–
Citrogypsum	0.2–1.7	0.13	–	0.1–0.15	32–43.6	0.1–0.4	0.07	38.3–55.5

Clay is a naturally occurring mineral, characterized with unique molecular-sorption and ion-exchange properties; by means of chemical and structural modification the performance parameters of the mineral can be purposefully altered, so that it can be used in artificial soils mixes production.

Sand is crushed and water-worn rock particles; it can considerably improve the physiological properties of a soil mix. Sand provides the moisture and air permeability of a soil mix and increases the heat penetration.

Vermiculite is a naturally occurring mineral from a hydrated mica group; it has a laminar structure and can

easily imbibe or produce water, creating the optimal humidity of soil for the proper nutrition of root systems.

Citrogypsum is a citric acid production waste; it contains the elements, necessary for vital activity of plants, such as S, Si and Ca, Mg, and blending well with the organic component of an artificial soil mix, improving its efficiency.

Wet magnetic separation waste (WMSW) of ferruginous quartzites from Lebedinsky MPP is a mining waste from the beneficiation process of iron ore raw materials. In its grain-size composition the WMSW corresponds to technogenic sands. Its application contributes to improving a number of soil mix's parameters – microclimate, mechanical composition and structure, and allows optimizing its grain-size composition and water-physical properties.

As an organo-mineral component the biocompost of black soldier fly maggots was used, which is a fine-grained loose non-caking brown mass with the pronounced muddy and woody scent and a trace of ammoniac compounds. Biocompost is a product of conversion of a specially prepared substrate, which contains powdered sawdust, off-grade foodstuffs from chain stores and nongrade grain, with black soldier fly maggots. The chemical composition of the biocompost is presented in Tab. 2.

**Table 2.** Chemical composition of biocompost, wt. %

P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	carbon	microelements	CaO	MgO	water
1–3	1–3	15–45	1–6	0.7–2	0.3–0.5	20–50

7 compositions of artificial soil mixes, containing the following components, wt. %: clay was 20–40, vermiculite was 5–10, citrogypsum was 5–20, biocompost of black soldier fly maggots was 10–30, WMSW of ferruginous quartzites beneficiation was 5–20, sand was the rest, were designed and prepared [17]. Artificial soil mixes were prepared by stirring the initial components in a paddle mixer in accordance with formulations (Tab. 3). The prepared artificial soil mixes compositions were kept for 3 days at the constant temperature of 17–20 °C and relative humidity of 60 %.

**Table 3.** The component composition of artificial soil mixes, wt. %

No. of the mix	clay	vermiculite	citrogypsum	biocompost	WMSW	sand
1	35	10	10	15	20	10
2	25	5	5	30	10	25
3	35	5	20	25	10	5
4	40	5	15	20	15	5
5	20	10	20	25	15	10
6	30	10	15	25	15	5
7	35	5	15	5	20	20

**Control** is the typical chernozem of the Belgorod region

At the first stage of the research, the toxicological characteristics of the obtained experimental samples of artificial soil mixes were evaluated, with the use of common oats (*Avena Sativa L.*) seeds as a test object [18]. This method is based on the alteration of root

system growth due to ability of the roots to react to exogenous chemical action; this allows taking the roots length as a test function index. Phytotoxicity is calculated by comparing the roots length in the control sample and in samples under study. Phytotoxicity is considered to be proved, if the root system development inhibition effect is 20 % and more.

The findings of the research have demonstrated that the inhibition of root system development of *Avena Sativa L.*, grown on the samples under study, doesn't exceed 20 % in comparison with the control. So, the designed compositions of artificial soil mixes on the basis of industrial waste have no phytotoxic action on the development of higher plants.

Then using the prepared samples of artificial soil mixes, garden cress of the «Vesenny» variety was grown. For this purpose the 2 kg samples of soil mixes were placed in pots, the surface area was 0.1 m<sup>2</sup>, the seeding rate was 1 g/m<sup>2</sup> at the depth of 0.5–1 cm. The experimental research was triplicated.

The plants of garden cress were gathered in 10 days after full seedling emergence, cleared from soil and weighed. The crop yield indices are presented in Tab. 4.

**Table 4.** Crop yield indices of garden cress grown on experimental artificial soil mix compositions

Artificial soil mixes compositions	Crop yield, kg/pot	Crop yield increase	
		kg	%
Control (soil)	0.15	–	–
1	0.21±0.005	+0.06	40.0
2	0.18±0.005	+0.03	20.0
3	0.15±0.005	–	0
4	0.19±0.005	+0.04	26.7
5	0.14±0.005	–0.01	–6.7
6	0.14±0.005	–0.01	–6.7
7	0.19±0.005	+0.04	26.7

The research findings have demonstrated that using multicomponent compositions of artificial soil mixes with the use of industrial waste provides the intensive development of plants. Compositions 1, 2, 4 and 7 form a nutrient-rich fertile soil mix, which provides the proceeding of physical-chemical processes between all its components, which increases the crop yield of garden cress by 40, 20 and 26.7 % in comparison with the control sample. This allows recommending the designed soil mixes compositions for using in growing plants under production conditions or at the biological stage of technologically disturbed lands recultivation.

Designing the compositions of artificial soil mixes opens up a new area of industrial waste utilization, which would contribute to reducing the amounts of its generation and storage, creating low-waste and non-waste production technologies and decreasing anthropogenic stress on the environment.

## 4 Conclusions

The current state of the human development requires large amounts of natural resources, which are then

returned to the environment in the form of production and consumption waste. Nowadays the problem of waste recycling is of high priority all over the world. It is known that 89 % of the waste, generated in the Belgorod region, is of the mining and metals sector and chemical industry. At present such waste doesn't find any application and is dumped at landfills, tailing dumps and sludge depositories. At the same time about 11 % of land resources in the world are disturbed lands, which require recultivation processes.

The authors have suggested a method of using artificial soil mixes, containing industrial waste.

The designed compositions of artificial soils contain the following components, wt %: clay was 20–40, vermiculite was 5–10, citrogypsum was 5–20, biocompost of black soldier fly maggots was 10–30, WMSW was 5–20, sand was the rest.

According to phytotoxic research findings with the use of *Avena Sativa L.* seeds as a test object, the compositions of artificial soil mixes on the basis of industrial waste were designed, which have no phytotoxic action on the development of higher plants.

It is demonstrated that multicomponent compositions of artificial soil mixes with the use of industrial waste can form a nutrient-rich fertile soil mix, which would provide the conduct of physical-chemical processes between all its components, which increases the crop yield of garden cress by 20–40 % in comparison with the control sample.

The designed soil mixes can be used when carrying out the biological stage of recultivating soils during restoration of technologically disturbed lands.

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