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The influence of the mixture of vermicompost and sulphur-perlite-containing waste on the yield and the quality of crops

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Abstract

Any type of material that increases soil yield, both qualitatively and quantitatively, to strengthen the soil and increase its fertility is called fertilizer. The current study examines the production of a new effective fertilizer. Results presented involve effects of new bioorganic-mineral compositions obtained from the combination of vermicompost and sulphur-containing waste from sulphuric acid production on the yield and quality of tubers (beets, carrots). An increase in the yield of tubers has been found to be 1.13–1.25 times when the bioorganic-mineral composition (~20 Mg·ha^{-1}) is introduced into the sierozem (serozem) soil. The best results are obtained with mass ratios in the range 30–45 and 55–70 for vermicompost and sulphur-perlite-containing waste, respectively. The effectiveness of the mixture of vermicompost and sulphur-containing waste is explained by the increased synergistic interaction of these components. The proposed composition has high structure-forming, water-retaining, nutritional and biologically active properties.

Key words: *crops quality, root vegetables, sierozem soil, soil fertility, substrate, sulphur perlite-containing waste, vermicompost, yielding*

INTRODUCTION

The soil system, as compared to other components of the biosphere, is the main environment that accumulates the pressure from the flow of industrial, agricultural, municipal emissions and waste [ALVAREZ 2005]. Under the rapidly growing pressure of the technogenic press, the soil surface begins to lose the possibility of fulfilling its most important role of a buffer and detoxicant. One of the main causes of the observed phenomenon is the predominance of destructive processes in the soil system over its biological productivity. On a global scale, crops yield reduces every year as a result of soil degradation and humus stocks depletion. Humic substances are the main source of nutrients and their presence determines soil fertility [CHRISTOPHER, LAL 2007; TREVISAN *et al.* 2010]. The main contribution to the yield of crops alongside the content of humic substances is provided by mineral components. They increase soil resistance to degradation. Humus and mineral substances in aggregate improve water-physical, water-temperature, physico-chemical and other soil properties.

One of the most important measures to increase soil fertility and the productivity of crops is the use of effective fertilizers and ameliorants [MAGUGU *et al.* 2018; MUSTAFAYEV 2015]. A lot of fertilizer-ameliorative agents are obtained on from the following materials: manure of cattle or bird droppings and phosphogypsum [GHOSH *et al.* 2004]; phosphogypsum and pyritic cinder [LU, TIAN 2017]; manure or bird droppings and terrific rock; terronic rock and sulphuric acid; manure or bird droppings and glauconite; phosphogypsum and slightly mineralized clay mud; drilling mud containing clay, drill rock, and crude oil [MOHAMMADI--SICHANI *et al.* 2017].

The drawback of traditional agents used in agriculture is their poor ameliorative and fertilizer efficiency in the first year of application [MURGESE *et al.* 2020; PAN *et al*. 2019; YUAN *et al*. 2020]. This is due to the fact that most of the compounds are present in inaccessible forms. In addition, untreated manure or bird droppings contain weed seeds that reduce crop yields and add various pathogenic microorganisms.

In order to prevent these shortcomings, the most expedient and promising technique is the use of compositions that have both fertilizer and ameliorative activities.

Eco-friendly non-conventional bioorganic fertilizers represent a special perspective for introduction to agro-production. They provide alternatives to replace traditional fertilizers, which usually contain some pollutants of different nature. For example, the uncontrolled use of nitrogen fertilizers, including heavy metals in significant amounts (60 kg of active substance per 1 ha), suppresses the natural biological processes of nitrogen fixation in the soil. This is one of the reasons for the accumulation of nitrates and nitrites in plants [ANGIN *et al*. 2011].

The purpose of this work is to discuss the production of new effective fertilizer-ameliorative agents based on vermicompost and sulphur-containing waste from sulphuric acid production.

MATERIALS AND METHODS

A mixture of vermicompost and sulphur-containing waste from sulphuric production has been used for the development of non-traditional complex bioorganic fertilizer.

Seroprelite-containing waste is a low-toxic and odourless substance consisting of the following environmentally friendly components: sulphur and perlite, gypsum and hydrated lime which do not pose a health hazard to biota, including humans. Perlite is a highly porous mineral of natural origin. It is widely used as an ameliorant and substrate in agricultural production to improve soil physical and chemical properties, i.e. it promotes aeration in soil and increases the capacity of cation exchange. With its presence, the earth does not cake, does not form a crust on its surface, remains friable, maintains a large moisture capacity, absorbing excess water from soil, which is then released gradually. Perlite has chemical inertness, and it is not exposed to microorganisms, insects and rodents. As an insecticide, it causes the death of pests. Perlite is a variety of natural silicate rocks which is absolutely safe for humans and does not cause allergic reactions and skin irritation. Perlite contains silicon oxide (78.1%), aluminum oxide (12.3%), sodium oxide (3.2%), potassium oxide 4.4%), iron(III) oxide (0.7%), iron(II) oxide (0.3%), magnesium oxide (0.06%), titanium oxide (0.1%), sulphur oxide (0.1%), gypsum and lime (in terms of calcium oxide 0.7%). Gypsum and lime are well--known ameliorants.

Sulphur regulates oxidation-regenerative processes in soils. It is used as an ameliorant, fertilizer which increases the yield of plants. Sulphur is a necessary microelement for plants, and it is part of proteins, enzymes and amino acids. When introduced into the soil under the influence of sulphur bacteria, sulphur can be oxidized to sulphuric acid. The content of elemental sulphur, in combination with its compounds (thiosulphate, sulphate, polysulphide) in sulphur-perlite-containing waste, is 10–20%.

In this work, the sierozem soils of Turkestan Region, the Republic of Kazakhstan, with the content of common humus in the layer (0–40 cm) of 1.0–1.2%, total nitrogen of 0.09–0.18%, mobile phosphorus of 9.0, 1–26.0 $mg \cdot kg^{-1}$, the amount of exchange bases of 23.6–26.9 $meq \cdot (100\ g)^{-1}$ of soil, the pH of the aqueous extract of 6.5 were used for conducting of the experiments. It is characterized by unfavourable physical properties, namely, low structure of the arable layer which when drying on its surface forms a dense crust.

Full-scale studies have been carried out on plots of 45 m^2, with an accounting of 27.5 m^2. The experiments have been repeated four times. Testing, observation and biometric measurements were implemented during the growing season according to a well-known method of conducting experiments with fertilizers [RAKUTKO *et al*. 2019].

Fertilizer-ameliorative agents are introduced locally in the form of a nest, as well as scattering, followed by mixing with a soil layer of 0–20 cm. The experiments have been repeated four times with a randomized distribution of plots within the option. The vermicompost was obtained in an accelerated manner [DOMÍNGUEZ 2018; MUNROE 2007]. To activate the vermi-technological process, calcium peroxide was added to the composition of the processed substrate. Since it slowly dissolves in the water-containing system, calcium peroxide releases oxygen and promotes aeration of the entire volume of the substrate. At the same time, anaerobic processes are inhibited, which are sources of environmental pollution by harmful substances. This improves the working capacity of producer-worms. The final products (O_2, H_2O, $CaCO_3$), formed during the decomposition of calcium peroxide, are harmless to biological resources.

In the vermi-technological process, waste from livestock farms and plant growing farms, food waste, leaf falls and others have been used as a substratum. The process has been carried out at a temperature of 15–25°C by using the red Californian worm (*Eisenia foetida*) in an amount of 250 thous. pcs. per 1 m^3.

For laboratory and analytical studies, soil and plant analyses have been implemented according to methods generally accepted in soil science, agrochemistry and ecology [BASHOUR, SAYEGH 2007; ZHANG *et al*. 2019]. The determination of soil fertility has been determined by bio tests; the content of organic substances by the Tyurin method; pH_{KCl} has been defined according to Kappen, whereas total nitrogen according to Kjeldahl, mobile phosphorus and exchange potassium according to Kirsanov [GOST R 54650-2011].

Biochemical studies provide for the determination of solids content (thermostatic-weighted method) and sugar (according to Bertrand) in the leaves and roots of crops under study. Chlorophyll content in the leaves of carrots and beets has been determined by the spectrophotometric method in the "Spekol" spectrophotometer [KOZHEMYAKO *et al*. 2019].

To establish water resistance, fresh soil samples were selected by the square method. Then, soil aggregates were taken from them and placed in cells with holes of similar size in aggregates. To maintain the soil aggregates, pins covered with phosphorus are placed below the cells. The system was irradiated with UV radiation, and the number of aggregates destroyed in water has been recorded by the number of luminous points [FEDOTOV *et al*. 2006]. As the results of the experiments show, the introduction of vermicompost into the soil increases the water-resistance of soil particles. The water resistance value for the control experiment is 15 ±3%, and for the soil with the vermicompost, it is 74 ±2% (8 Mg·ha^{-1}). The results obtained have been statically processed using Microsoft Excel.

RESULTS AND DISCUSSION

A comparative analysis of the composition of manure, compost and vermicompost (bio humus) has been carried out. Such data have been necessary for the preparation of a support medium for the vermicomposting process.

Results of chemical determination of the manure composition of various animal species and products of their processing – compost and vermicomposts are presented in Table 1.

From all types of manure, the most valuable organic fertilizer is camel manure due to its nutritional value and chemical composition. Camel manure is practically odourless and characterized by high airiness, more friable and less moisture (from 5 to 8%). The content of organic substances in it is more than 29.0–32.7% compared to the manure of other animals.

As the results of experimental studies have shown, the vermicompost differs from compost in its composition, microbiological, chemical and other properties. The vermicompost does not conserve seeds of weed plants, as well as does not contain helminths and other pathological microorganisms.

Vermicompost is a dry organic, loose, finely granulated mass almost black with a granule size of 1–3 mm. Vermicompost contains vitamins, enzymes and a large amount of humic substances (up to 37% by dry weight). Therefore, it possesses high agrochemical and growth-stimulating properties: it increases the amount of nutrients (nitrogen, phosphorus, potassium) and microelements in the soil, improves its structure, protects vegetation from weeds and pests throughout the growing season, provides a stable high organic crop yield of excellent taste. In a long-term perspective (3–5 years), the fertilizer quickly restores fertility and is suitable for all types of soils. Vermicompost has exceptional physicochemical properties: water-resistance of its structure (95–97%) and full moisture capacity (200–250%). This enables it to be considered not only as a fertilizer but also as a perfect ameliorant and soil improver.

Table 1. Content of the main components in manure, composts and vermicomposts

Element of food	Manure type			
	horse	cow	sheep	camel
Manure				
Nitrogen	0.3–0.8	0.1–0.7	0.7–0.9	0.4–1.0
Phosphorus	0.2–0.7	0.1–0.6	0.2–0.4	0.4–0.9
Potassium	0.2–0.8	0.2–0.7	0.3–0.8	0.5–0.9
Calcium	0.2–0.3	0.3–0.5	0.3–0.4	0.4–0.5
Magnesium	0.1–0.2	0.1–0.2	0.1–0.3	0.2–0.4
Humidity	67.0–71.1	74.5–77.3	61.2–64.5	5.3–8.4
Organic substance	24.6–25.9	19.9–20.2	30.8–31.5	29.0–32.7
pH	7.6–8.0	7.7–8.1	6.8–6.9	6.7–6.8
Compost				
Nitrogen	0.5–0.9	0.4–0.8	0.8–0.9	1.2–4.0
Phosphorus	0.3–0.8	0.5–0.75	0.4–0.5	0.8–0.9
Potassium	0.6–0.8	0.4–0.8	0.3–0.9	0.9–1.0
Calcium	0.3–0.5	0.5–0.7	0.4–0.7	0.5–0.7
Magnesium	0.1–0.25	0.17–0.28	0.3–0.4	0.4–0.5
Humidity	70.05–72.5	77.9–80.1	62.85–65.0	7.0–9.0
Organic substance	25.9–31.7	20.09–21.9	30.17–33.05	31.0–40.0
pH	7.5–8.2	7.9–8.8	6.8–7.05	6.8–7.0
Vermicompost				
Nitrogen	1.0–3.0	1.0–2.5	1.0–2.0	1.2–4.0
Phosphorus	1.3–2.8	1.3–2.5	1.3–2.0	2.0–5.2
Potassium	1.2–4.4	1.2–3.8	1.2–3.0	2.0–5.2
Calcium	4.0–6.0	4.0–5.0	3.8–5.0	4.8–7.2
Magnesium	0.5–2.3	0.5–1.7	0.3–1.0	0.3–0.9
Humidity	40.07–50.05	57.7–60.8	60.95–72.0	7.05–9.3
Organic substance	24.3–30.75	23.1–28.13	31.5–34.0	32.07–34.05
pH	6.5–7.1	6.7–7.28	6.6–6.9	6.8–6.9

Source: own study.

We have previously investigated the properties of vermicompost, sulphur-containing waste of sulphuric acid production, as well as their mixture. Fertilizer and reclamation properties have been determined. The optimal ratio of vermicompost and sulphur-containing waste is given in Table 2. The mixture has been given the name of "Vermiser".

Table 2. Optimal and limited content of components in fertilizer-soil improver

Sample No.	Minimum component content (weight %)	
	sulphur-containing waste	vermicompost
1	55.0	45.0
2	62.5	37.5
3	70.0	30.0

Source: own study.

From scientific and practical interest point of view, the effect of the "Vermiser" on widely consumed crops like beet and carrots has been examined. Experiments used a "Bordo-237" beet variety and "Shanten" carrot variety. Due to the fact that stimulants have a significant influence on the growth and development of plants in the very early stage, we have conducted pre-sowing seed treatment in the case of beets and carrots.

As it is known, a major role for the further development of any representative of the biota is played by profound changes in the seed germ, which ultimately leads to a change in the course of biological processes at the cellular level. This increases the activeness of enzymes, accelerates photosynthesis, increases the carbohydrate content in leaves and stimulates the production capacity.

To some extent, the acceleration of seed germination prevents the depressing effect caused by weeds.

On the basis of experimental studies, a number of studies have shown the possibility of changing crop yields and growth by activating substances [KWIATKOWSKI, JUSZCZAK 2011; MONDAL *et al*. 2012; NOMAN *et al*. 2018]. The change in growth depends on the concentration of drugs applied. If the acceleration of growth is observed at small ones, then for large ones, inhibition is observed on the contrary. In this regard, for each culture, it is necessary to establish the optimal concentration limits for substances used to regulate growth experimentally.

Table 3 shows the experimental data obtained in the study of the effect produced by different concentrations of "Vermiser" on the germination energy and the germination of carrot and beet seeds respectively in the pre-sowing treatment of seeds. The maximum increase in seed germination energy of both carrot and beet is observed at the drug concentration of 0.001–0.0001%. When the concentration of the preparation is 0.01%, the seed germination becomes comparable with the control, whereas above this concentration, growth processes are inhibited.

Table 3. Results of pre-sowing experiments of carrot and beet seeds with solutions of "Vermiser"

Seeds of	Germination values at the concentration of "Vermiser" (%)				
	10^{-4}	10^{-3}	10^{-2}	10^{-1}	0
Beet	60/90	75/100	70/86	56/72	58/71
Carrot	58/93	64/100	53/88	40/76	43/68

Explanations: in the numerator – germination energy (%), in the denominator – germination (%).
Source: own study.

The reports from phenological research have shown that during the processing of seeds and plants, "Vermiser" speeds up the appearance of early and friendly shoots for 3–4 days, the formation of 3 and 4 leaves for 3–4 days, the formation of root crops for 5–6 days, technical ripeness of root crops for 8–10 days. The earliest onset of phenophases in beets and carrots has been noted in a variant with the complex treatment of plants, that is with a pre-sowing seed treatment in the phase of root crop formation.

Pre-sowing soaking of seeds in "Vermiser" solutions for two days increases the energy of germination. The most optimal concentration of the drug, affecting the seeds germination, both beets and carrots, is a concentration of 10^{-3}%. At this optimal concentration of the drug, the density of plant standing within 360–370 thous. pcs. of beet per ha and 1025–1030 thous. pcs. of carrot per ha is achieved.

Biochemical analysis has established the content of chlorophyll in beet and carrots. As it is known, chlorophyll plays an important role in photosynthesis. In this regard, we studied the effect the drug had on the chlorophyll content in the leaves of carrot and beet. The results are shown in Table 4.

Table 4. Content of dry matter, sugar, and chlorophyll (%) in leaves of investigated crops in the phase of the root crop formation

Type of treatment with "Vermiser"	Content (%)		
	dry substances	sugar	chlorophyll
Beet			
Water treatment (control)	11.9 ±0.1	2.2 ±0.05	26.1 ±0.1
Pre-sowing seed treatment	12.8 ±0.1	2.5 ±0.05	32.8 ±0.1
Treatment only in the phase of the root crop formation	12.0 ±0.1	2.6 ±0.05	29.8 ±0.1
Complex treatment (pre-sowing and in the phase of root crop formation)	13.1 ±0.1	3.0 ±0.05	34.4 ±0.1
Carrot			
Water treatment (control)	9.7 ±0.1	22.2 ±0.1	3.6 ±0.05
Pre-sowing seed treatment	10.0 ±0.1	24.0 ±0.1	3.7 ±0.05
Treatment only in the phase of the root crop formation	10.2 ±0.1	23.0 ±0.1	3.8 ±0.05
Complex treatment (pre-sowing and in the phase of root crop formation)	11.0 ±0.1	24.3 ±0.1	4.0 ±0.05

Source: own study.

Table 4 shows a favourable effect on biochemical indicators of beets and carrots of complex treatment of seeds and plants with 0.001% solutions of the drug.

In connection with the fact that the morphophysiological trait, which significantly influences the accumulation of sugar, is the number of conducting beams in the petioles of leaves of beet, the reliance of this indicator on the effect of biologically active drugs has been studied (Tab. 5).

Table 5. Effect of "Vermiser" on growth and development of beets

Option	Quantity of conductive beams in pieces	Quantity ± to control in pieces	Biometric indicator		
			length (cm)	diameter (cm)	root index
Control (water)	22.0	–	11.7±0.1	6.8±0.2	1.72
Treatment with "Vermiser" (0.001%)	27.4	5.4	14.2±0.1	7.7±0.2	1.91

Source: own study.

An increase in the number of conducting beams in cuttings of leaves in the presence of the biologically active drug in comparison with the control has been established. In the complex treatment of crops with a biologically active drug, the difference with the control is 5.4 pieces, which indicates an increase in the volume of transported substances; i.e. it promotes more intensive growth and development of plants.

When seeds were soaked in growth regulator solutions, optimal growth-stimulating concentrations (0.001%) showed active growth of roots and stems of beet and carrot seedlings in comparison with the control. The pre-sowing treatment of the seed by the drug synthesized by us had a significant effect on the morphology of both beets and carrots.

Plants which develop from seeds treated with "Vermiser" grow and develop better, enter the phase of root moulting earlier, and their beaming and economic ripeness takes place earlier. These plants have shown major development of leaves, which is evident from the growth rate of the assimilative surface of carrot leaves and table beets. According to literature data given by HOFFMANN and KLUGE-

-SEVERIN [2011], the larger the quantity and surface of leaves at the beginning of the growing season, the larger the yield of beet.

Our experimental data are consistent with the literature [BOINCEAN, DENT 2019; MONDAL *et al*. 2012], a more intensive growth of the tops and the assimilative surface of the leaves have a positive effect on the formation of root crops (Tab. 6).

Table 6. Effect of "Vermiser" on the formation of beet and carrot yield

Option	Beet		Carrot	
	total yield ($Mg·ha^{-1}$)	marketability (%)	total yield ($Mg·ha^{-1}$)	marketability (%)
Control	50.2	88.7	35.1	82.4
Vermicompost, 8 $Mg·ha^{-1}$	54.7	92.4	38.2	86.1
Sulphur-perlite-containing waste, 15 $Mg·ha^{-1}$	52.9	90.0	36.0	79.9
Drug "Vermiser", 20 $Mg·ha^{-1}$	62.8	93.3	39.5	87.5

Source: own study.

Table 5 shows the increase by 2.5 and 0.9 cm in the length and diameter of root crops when a stimulant is used, e.g. "Vermiser", at the optimal dose of 0.001%.

The increase in the diameter of beetroot crops also outstrips the control when the seeds are soaked in solutions of the synthesized stimulant. A similar effect has been established for carrots.

Thus, when the seeds of carrots and beets are treated with "Vermiser", it increased the root system, the area of a leaf surface and accelerated the processes of photosynthesis. In this case, since photosynthesis is a basis for plant growth and development, accumulation of chemical compounds and, consequently, biomass can be associated with other physiological indicators, including the change in the chemical composition. An increase in the volume and mass of roots and root crops leads to an intensification of their absorption and synthesis capacity, as well as more intensive mass transfer of ions and nutrients through the plant. This contributes to the intensive sprouting and the formation of new organs, and an increase of yields and the quality of marketable products (Tab. 6).

Other observations include the acceleration of flowering and ripening of cultures, and the stimulation of root system development. The absence of pathogenic microflora, eggs and larvae of helminths introduced into the soil enabled to increase the ecological safety of crop yields. The developed new fertilizer-ameliorative agents are a source of nutrient elements for plants. They directly influence the formation of agrophysical (structure, bulk mass, water retention capacity, etc.), physical, chemical and biological properties of the soil.

CONCLUSIONS

As mentioned earlier, the paper studied the production of a new effective fertilizer. Thus, on the basis of laboratory experiments and production tests, the optimal way of applying "Vermiser" as an ameliorant fertilizer in agricultural practice was found. A mixture of vermicompost and sulphur-containing waste from sulphuric acid production increases the quantity, quality and market presentability of products, which is important for the production of food crops like beets and carrots. The best results were obtained with vermicompost and sulphur-perlite-containing waste mass ratios of 30–45 and 55–70, respectively.

The increase in yield and improvement of taste of the studied crops are associated with the enrichment of soil with humic acids (main components of bio humus) and other nutrients, as well as with the improvement of the soil structure (elimination of the formation of a dry, dense cortical layer), which allows to create favourable conditions for optimal aeration and moisture capacity. The improvement in the supply of plant tissues with water can also be explained by the presence of a sufficient amount of silicon compounds in the used sulphuroplite-containing material. As it is known, silicon in plants is deposited in the epidermal cells in the form of a double cuticular-silicon layer, and the formed silicon-cellulose membrane thereby creates conditions for more economical use of moisture. In addition, mono silicic acids are exposed to water in the polymerization process, which can also be an additional source of moisture necessary for the growth and development of plants.

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