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Intensification of bioproductivity of agricultural cultures by adding natural zeolites and brown coals into soils

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ABSTRACT

On the basis of relevant research works, the paper discuses positive effect of the utilization of non-traditional natural resources, the so-called agronomical ores, i.e. mineral fertilizers, in order to increase the productivity of crops and improve the physical and chemical properties of the soil. The effectiveness of such fertilizers is their complex positive influence on the properties and modes of the soil and, in general, on a system "soil-plant". The paper shows the prospects of the use of zeolite-based substrates, brown coal and soil on the growth of test crops - barley. The conclusions reached in this study should be considered encouraging with regard to solving the problem in question.

Introduction

Modern agriculture focuses on such important and vital problems as necessity to increase the productivity of all agricultural species without increasing application of mineral fertilizers to the soil, to increase soil fertility and obtaining environmentally safe agricultural production.

Worldwide agricultural practices demonstrate that among the many agronomical factors, fertilizers are of supreme importance in increasing the crop yield and soil fertility. It is impossible to achieve consistently high yields of the required quality without the use of fertilizers, without introducing nutrients, – the basic element for growth and improvement, – in a balanced and strictly prescribed order during the entire vegetation period [1].

Balanced nutrients for plants with macro- and microelements regulate numerous processes of their metabolism and play a key role in formation of the yield and its quality.

At the same time, in recent years the content of mobile forms of macro- and microelements in the soil available to plants declined significantly, as a result of a sharp decrease in the amount of fertilizers applied in all regions of the country; their total content in the soil was also somewhat reduced, the areas of arable and unsown lands with low content of mobile forms of macro- and microelements significantly increased, chemical composition and nutritional value of crop production decreased. The low level of application of chemicals in

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agriculture adversely affects not only the plant yield. Reduced humus content and soil acidification significantly activates the processes of mobilization of soil toxicants, their penetration into plants, which ultimately negatively affects the yield and quality of products [2].

As the experience of developed countries shows there is no alternative to fertilizers in enhancement of the yield of agricultural cultures and soil fertility. Fertilizers have multifaceted direct and indirect effects on soil and plants, they feed the plants as well as mobilize soil nutrients, increase the intensity of chemical and microbiological processes in the soil and change the properties of the soil [3,4].

Extensive studies of agronomical ores are conducted in our country [5]. Stratigraphic location of productive layers of agronomical ores raw is established and possibility of their utilization in agriculture is determined. It is established that there is a plenty of agronomical ores on the territory of Georgia and favorable conditions exist in order to produce local mineral and organic fertilizers, enlarge and develop a basis for their raw materials [6,7]. Among them the most widespread are deposits of limestone, dolomite, marl, chalk, peat, brown coal, gypsum, and also natural zeolites that are of particular interest for their usefulness in agriculture.

The works of past years demonstrated that adding natural zeolites of sedimentary origin into soil is widely practiced for the purpose of growing different agricultural cultures and enhancing their productivity [8–11].

Usually, natural zeolites are used in plant growing processes either in natural form or in combinations with mineral or organic fertilizers.

Natural zeolites are natural mineral fertilizers that facilitate significant (up to 50%) increase in the yield of agricultural crops. They should be used in both open grounds and greenhouses.

The researchers who accumulated accumulated experience in applying natural zeolites in agriculture revealed their following qualities [8,12]:

- Zeolite keeps humidity in the soil, retains it for a long time and supplies plants with it gradually and continuously;
- The use of natural zeolite halts fertilizers washing out of the soil, restores and increases capability of the soil to improve, metabolism of plants;
- Zeolite prevents diseases of plant roots. It is a source of microelements and heat regulator of the soil.
- The presence of zeolites in the soil reduces content of nitrates in fruits by 7–38%, increases yield of vegetables by 50–70% in average, increases content of sugars and vitamin C in fruits;
- By improving the soil structure zeolites accumulate and regulate soil nutrients. Accumulation and regulation of nutrients is especially important for those ions that are easily washed out - NO_3^- and NH_4^+, or rapidly transform themselves into inaccessible to plants forms: phosphorus, iron, zinc, manganese, etc. Thus, the presence of zeolite reduces the nitrogen leaching out of soil 4–5 times. As a result, it enables plants to utilize efficiently the nutrients and fertilizers present in the soil;
- Zeolite reduces absorption of toxic substances and radionuclides by plants from the soil by sorbing radionuclides and heavy metals presented in the soil and transferring their mobile forms in a bound state. They are not washed out of the soil and not absorbed by the plants;
- Zeolites promotereducing nitrification of nitrogen in the soil and decrease the nitrate content in the crop significantly;
- The use of zeolite-containing substrates in greenhouses increases yield of vegetables up to 60%, raises the vitamin content up to 70%, reduces the amount of nitrates by 60%. Zeolite substrates are especially effective in modern systems of drip irrigation.

The present study aimed to develop an efficient substrate not containing soil, because of worldwide trend towards the creation of substrates for cultivation of agricultural plants with minimum utilization of soil (transition from plant growing to plant production). For the cultivation of various agricultural cultures greenhouse soils (substrates) are widely used consisting of various components, the number of which, for the most part, does not exceed four components.

Substrates, in their turn, are divided into two groups: substrates containing the soil and substrates that do not contain the soil. At present the latter are preferable [9].

In the present study, brown coal from the Akhaltsikhe (Georgia) deposits was used as a substitute for soil. The given coal belongs to the humus-sapropelite group and to the class of lean brown coal [13]. They are not used in practice but they contain a large amount of organic components in the form of humic substances. An attempt was made to use them in combination with natural zeolites assuming that the presence of these minerals in the substrate would contribute to transferring organic substances contained in the brown coal into the matter absorbable by plants [14].

Objectives and methods

Natural zeolites of the sedimentary origin (clinoptilolite), soil, and brown coal served as the raw materials for preparation of the substrate.

Natural zeolite – clinoptilolite tuff from Tedzami deposits, Khandaki site (Georgia). The content of the main mineral in this rock varies within the ranges of 70–80%; calcium prevails in the cation content (Table 1) [15].

Clinoptilolite (Cl) belongs to the group of heulandite zeolites [15]. Minerals of this group are the most widespread

Table 1 – Characterization of zeolite.

IUPAC crystal chemical formula	$\|Ca_4 (H_2O)_{24}\|$ $[Al_8Si_{28}O_{72}]$-HEU	
Crystal chemical data	monoclinic, *Cm* a = 17.718 Å, b = 17.897 Å, c = 7.428 Å, = 116.42°	
Framework dencity	17.1 T/1000 Å^3	
Channels along axis	[001]	10-ring 3.1 Å × 7.5 Å + 8-ring 3.6 Å × 4.6 Å
	[100]	8-ring 2.8 Å × 4.7 Å
	Variable due to considerable flexibility of framework	

zeolites occurring in nature. The crystal structure of clinoptilolite is characterized by quite open channels formed with ten- and eight-membered tetrahedral rings arranged in three directions: the channels parallel to the C axis have the following dimensions: 0.705 × 0.425 nm and 0.460 × 0.395 nm, respectively. Eight-membered channels, arranged in parallel and at 500 angle to the A axis, have diameters of 0.540 × 0.390 and 0.520 × 0.390 nm [16].

The meadow-brown soil with alkalescent reaction of its aqueous solution (pH = 7.3–7.9) was used in the experiment. The soil is characterized by a low content of humus (1.93–2.90%) and it belongs to the heavy loam by the granulometric composition [17].

The experiment was carried out in the vegetative vessels, in five versions, each in three repetitions. For testing the fertility of the substrate, barley "Alaverdi 1" was used as the test plant [17–19].

In the first version the soil (object of comparison) was used as the standard. In the second version the substrate was produced by mixing of finely-grained (up to grain size<1 mm) zeolite and soil. The third version was with brown coal and soil. The fourth version was the main, similar to the second embodiment, but instead of soil used brown coal. In the fifth version the soil, brown coal and zeolite were used.

Before starting the experiment sowing qualities of barley seeds - germination and viability were determined. Germination capability was determined by the number of seeds, which germinated in the given time for this culture (in this particular case it is 7 days). It is based on the percentage of the total number of seeds taken for sowing and indicates the ability to generate normally developed seedlings under optimum conditions of germination. Germinating energy points at friendliness and germination rate of seeds. It is defined in conjunction with the analysis of germination, but the calculation of normally germinated seeds is carried out earlier. Moistened silica sand was used as bedding for germination. The experiments confirmed the good sowing quality of barley seeds (98.5%), which were used later in the above-mentioned variants of the experiment [20].

Results and analysis

The following biometric parameters have been determined: germination energy (GE), relative value of germination energy (RVGE), germination (G), relative value of seed germination (RVSG), height of sprout (HS), relative size of height of sprout (RSHS), rate of germination (RG) and intergrowth (IG). Germination energy for the seeds barley was determined in three days after sowing but germination on the seven day. The results of determination of energies of germination are given in Table 2.

Relative germination of seeds of beans and barleys (RGBB) and relative size (height) of barley sprout (RHBB) were calculated by the formulas given in work [21]:

$$RGBB\% = (NGex - NGc)/NGc \times 100,$$

where NGex is a number of germinations in the experimental version; NGc – a number of germinations in the control version, and

$$RHBB\% = (HGex - HGc)/(HGc) \times 100,$$

where HGex is a height of germination in the experimental version; HGc – a height of germination in the control version.

Analysis of the data given in Table 2 confirms that adding zeolites to the soil increases germination and growth potential of barley seeds.

The given parameters are even higher for the samples containing zeolites and brown coal. Variation of these parameters on the substrate occurs in the sequence:

Table 2 – Impact of substrate on seed germination of barley.

Type of substrate	Sowing	Type substrate				
		Soil	Brown coal- soil	Zeolite-soil	Zeolite-brown coal	Soil-brown coal-zeolite
GE	1st sowing	20	34	34	36	46
	2nd sowing	40	45	50	58	60
	3rd sowing	66	78	82	84	86
	4th sowing	70	70	71	76	80
	5th sowing	34	36	52	55	64
RVGE	1st sowing	–	0.4	0.7	0.8	0.9
	2nd sowing	–	0.2	0.25	0.45	0.5
	3rd sowing	–	0.3	0.24	0.27	0.31
	4th sowing	–	0.04	0.41	0.13	0.24
	5th sowing	–	0.02	0.33	0.09	0.18
G	1st sowing	36	40	48	52	50
	2nd sowing	46	49	50	76	68
	3rd sowing	78	80	84	92	98
	4th sowing	76	81	83	87	88
	5th sowing	50	66	76	80	86
RVSG	1st sowing	–	0.2	0.4	0.50	0.68
	2nd sowing	–	0.06	0.08	0.65	0.78
	3rd sowing	–	0.92	0.44	0.80	0.97
	4th sowing	–	0.17	0.07	0.39	0.46
	5th sowing	–	0.07	0.06	0.14	0.23

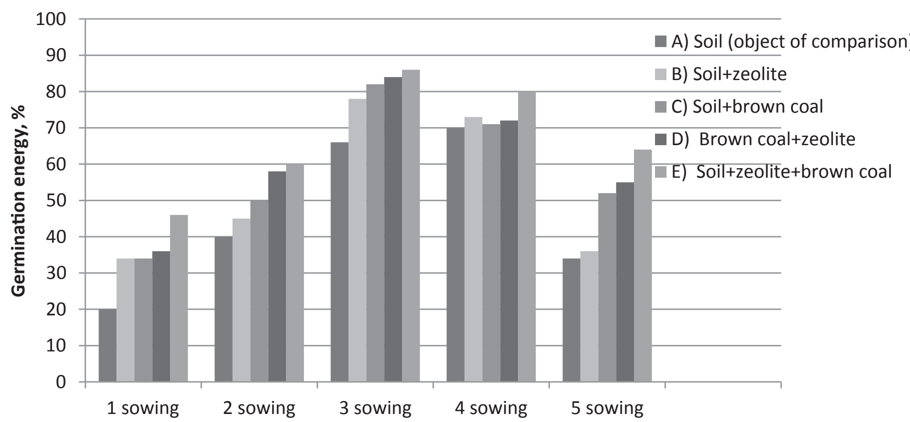

Fig. 1 – Change of a germination energy of a plant (%).

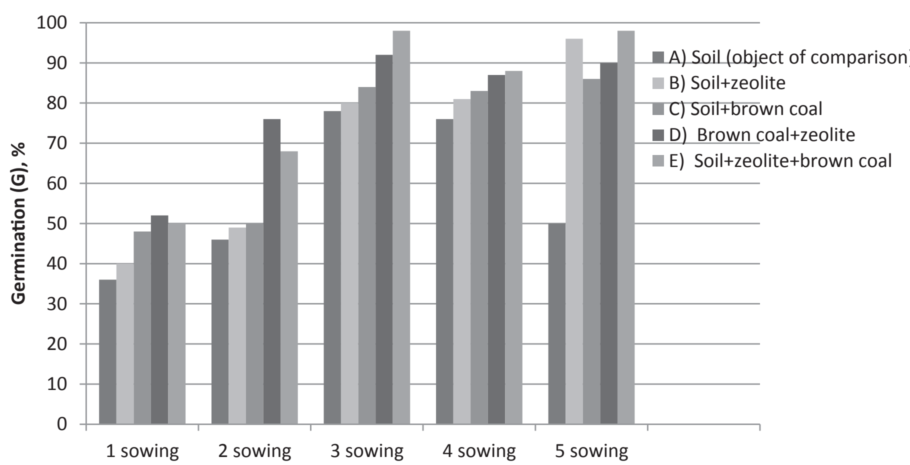

Fig. 2 – Change of a germination of a plant (%).

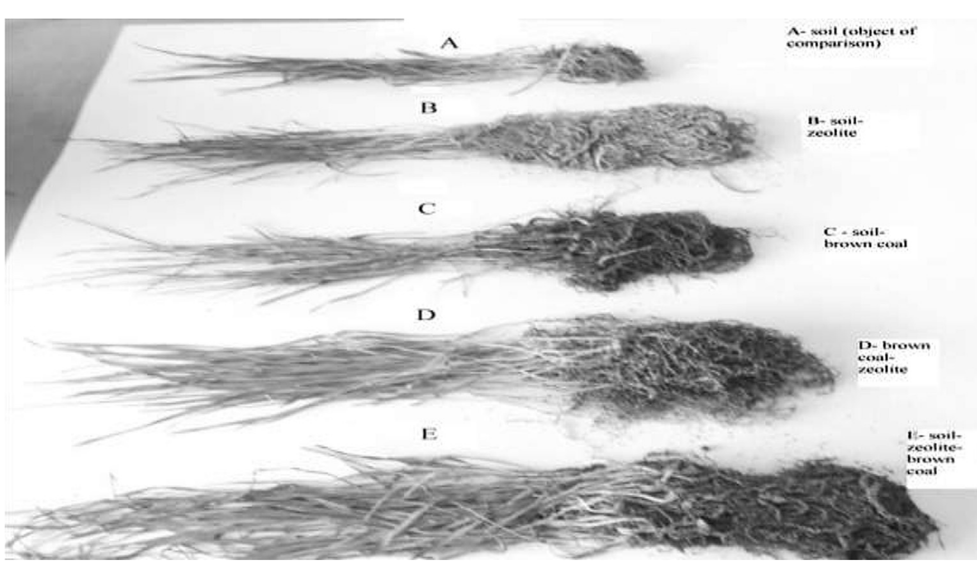

Fig. 3 – Sprouting barley on various substrates: A – soil (object of comparison); B – soil-zeolite; C – soil-brown coal; D – brown coal-zeolite; E – soil-zeolite-brown coal.

$$Soil(object\ of\ comparison) < Soil + brown\ coal < Soil + zeolite < Brown\ coal + zeolite < Soil + zeolite + brown\ coal.$$

Figs. 1 and 2 show the changes in germination energy and germination of barley on various substrates.

Comparing the data one can see, as it was expected, that during the period when the experiment was conducted, the root system of plants developed and grew, i.e. biological productivity (biomass) of barley increased. The high biological productivity of the substrate, can be tentatively associated with the formation of the microbial landscape favorable for plant growth and development that takes place in the system of Zeolite-organic compounds (Fig. 3).

Conclusion

Thus, the organic-zeolite substrate developed on the basis of heulandite-clinoptilolite tuff and brown coal is characterized by high biological productivity of plants grown on it, and has potential for long-term utilization in plant growing. The research results of the study should be considered encouraging with regard to solving the problem in question. In addition, the present work is of preliminary character and its results permit their implementation in agriculture. The research requires wider agrochemical experiments.

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