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IMPLEMENTATION OF NEW TECHNIQUE FOR PHYTO- AND CHEMICAL MELIORATION OF ACIDIC AND SALINE SOILS

The advanced technique for the reclamation of acidic and saline soils based on the integrated use of siliceous compounds for joint cultivation of cereals, legumes, and cruciferous plants has been implemented. Procedure for the use of chemical and phyto- ameliorants in different soil and climatic zones of Ukraine has been designed. The siliceous mixes with high ameliorative potential and optimal dosages for their application have been identified. Chemical and phyto- ameliorants have been comprehensively studied; their role in stimulation of the development of agriculturally useful microbiota has been determined, Agrophysical, agrochemical, and biological characteristics of soil have been improved, with toxicity and soil sickness reduced due to the use of siliceous mixes. The structure of crop rotation has been improved.

Keywords: acidic and saline soils, chemical and phyto-melioration, siliceous mixes, crops, and adaptive potential.

Soil is one of the basic elements of terrestrial life. As Jean Pierre Dostes, a famous environment activist, put it, the soil is the most valuable capital. The life and wealth of the whole complex of both natural and artificial bio-communities depend on the thin upper layer of the Earth. Being a part of the biosphere, the soil is a necessary condition for its existence, since none other components of the biosphere being capable of replacing the soil. The formation of 1 cm thick layer takes about 100 years. However, it can be lost during a year, as a result of negligence. At the end of the 20th century, the soil degradation turned really dangerous and nowadays, it is among the major threats that can trigger the global environment crisis. Therefore, remediation and effective use of soils are priority objectives of the mankind.

The acid degradation (decalcification) of soils has been reported for the major part of Ukraine. According to the State Agency for Land Resources of Ukraine, the acidic soils cover an area of about 5.5 million ha, including 0.64 million ha strongly acidic soils (saline $pH < 4.5$), 1.37 million ha medium-acid soils (saline pH 4.5—5.0) and 3.45 million ha weakly acid soils (saline pH 5.0—5.5). About 4 million ha acidic soils are occupied by pastures, grasslands, and other farming and hunting acreages. At the same time, according to the Soils Protection Institute of Ukraine, the area of acidic soils totals nearly 8.5 million ha [1].

Recently, both in Ukraine and throughout the world, more and more cases of secondary oxidative stress have been reported as a result of acid rains and imbalanced use of mineral fertilizers. Moreover, even the black humus earth that is neutral by its nature turns acid. Soil decalcification is accompanied with dehumification. Humus content has been established to decrease in all soil and climatic zones of Ukraine.

The acid soils are characterized by lesser content of calcium and magnesium and presence of aluminum and iron oxides which hamper the penetration of nutrients to the roots of plants. These soils are prone to compaction at the level of subsoil and cropland, porosity reduction, and failure of water-air regime. These soils are subject to misstructuring, crust formation, and erosion. The mentioned processes lead to in dropping yield, reducing use of nutrients by plants as a result of changes in root system development [7, 10], enhancing washout of nutrients, and inhibiting growth of plants and useful microflora.

Reclamation of saline soils is another relevant problem for Ukraine and other world countries [6, 8, 11]. According to data of the State Cadaster of Ukraine, the saline soils occupy an area of 1.92 million ha, including 1.71 million ha used for agricultural purposes. The area of alkalized soils is 2.8 million ha; they are located mainly in the steppe zone, with approximately 2/3 cultivated and nearly 0.8 million ha irrigated [1]. During irrigation, secondary alkalization of soils can occur as a result of sodium and potassium penetration into the soil complex.

The remediation of soils is based on ensuring an optimal pH level, a complete balance of humus and nutrients and removing harmful abiotic and biotic factors (salinity, phytopathogens, etc.).

The most environment friendly, efficient, and promising method of chemical melioration is the use of organic materials together with siliceous minerals of natural origin, with sapropel as organic material. Sapropel is unconsolidated sludge consisting of decomposed remains of aquatic organisms, which accumulates at the bottoms of freshwater lakes. Due to an alkaline reaction ($pH = 9.8$—10.2), sapropel effectively decreases soil acidity. In addition, sapropel is notable for a high content of organic nitrogen and phosphates Ca, K, and Mg. According to forecasts of environment experts, in order to remedy the Ukrainian black humus soils it is necessary to put 30—40 ton organic fertilizers per ha annually [2]. Previously, there were over 10 types of black mold. Nowadays, mold production is abandoned. Currently, animal waste slurry and carbamide are the most widely used fertilizers, however, they are known to contaminate the soil. Sapropel is the most environment friendly organic material. Increasing content of organic matter significantly raises effectiveness of mineral fertilizers, mitigates their adverse side effects, stimulates fixation of their residuals, and neutralizes harmful impurities.

Presence of siliceous natural minerals in the mixes, on the one hand, enhances adaptability of plants to abiotic and biotic stress factors, and on the other hand, materially improves agrophysical, agrochemical, and bioecological condition of soils [9].

Sowing of clover and sainfoin is considered an effective and environment friendly method for improving the properties of acid soils. Due to deep root system these crops transport calcium from deep layers and accumulate it in the cultivated layer. In addition, the above plants are notable for their favorable effect on the soil bio-ecologic properties as they enhance microbiologic processes in the soil, stimulate growth of nitrogen fixing microorganisms, inhibit growth of wild grass, pathogens, and pests.

This research is aimed at implementing the advanced technique for melioration of acidic and saline soils in accordance with the Conception for Fighting Land Degradation and the UN Convention to be implemented in Ukraine in 2014—2018.

The proposed technique based on synecologic principles combines chemical and phyto-melioration, ensures well-balanced nutrition system of plants, improves agrophysical, agrochemical, and biological properties of the soil. It should be noted that it addresses the problems of reducing soil sickness and toxicity and raising the adaptability of plants to adverse abiotic and biotic factors, including phyto-pathogens.

EFFECT OF SILICEOUS MIXES ON THE CROP ADAPTIVE CAPACITY DEPENDING ON SALINITY AND ACIDITY OF THE GROWING MEDIUM

A series of laboratory and field tests has been made for studying the effect of 4 mixes on adaptability of test plants depending on salinity: mix no.1 (90% sapropel, 7% rotten stone, 3% analcime); mix no. 2 (50% rotten stone, 25% potas-

Effect of Siliceous Mineral
of Maize Growth

Salinity, %		0	1	2	3	4	0	1	2	3	4	0
Mix no		Height, mm					Leaf area, cm²					
	0	165	148	114	115	99	7.0	6.1	4.1	4.4	4.3	151
	1	175	148	126	145	101	7.2	6.7	5.5	5.2	3.8	156
	2	175	152	136	135	111	7.0	6.9	5.4	5.4	5.2	151
	3	177	156	122	124	102	6.6	6.4	4.8	6.0	4.4	151
	4	168	144	112	102	87	7.1	5.7	5.1	5.1	4.3	148

sium silicate, 15% analcime, 10% sapropel); mix no. 3 (70% rotten stone, 30% analcime); and mix no. 4 (70% bog peat, 30% rotten stone).

The following test plants have been used for the laboratory tests: maize (*Zea mays* L., Favorite hybrid), sainfoin (*Onobrychis arenaria* (Kit.), *Fabaceae* L. family) and representatives of the cabbage family (*Brassicaceae* L.): typhon (*Brassica campestris f. biennis* D.C. × *B. rapa* L.), reddish and oil reddish (*Raphanus sativus* L. var. *oleiformis* Pers.), and winter rape (*Brassica campestris f.biennis* D.C.). The seeds were sown into vegetative pots with sandy growing medium [3]. The salinization was simulated by single watering with sodium chloride solutions having a concentration of 0 (reference); 1; 2; 3; 4%, after sprouting. Different levels of oxidative stress were simulated by regular watering of test plants with distilled water acidified by hydrogen chloride to $pH = 4; 5; 6; 7$. Growing conditions were as follows: temperature 22—30 °C, scattered solar radiation, and humidity 60—75%. The duration of tests was 21 days for maize and 30 days for other crops. Each test was repeated 4 times. The condition of maize plant was assessed by morphometric growth parameters (height of herb, root length, leaf area), dry weight of herbs and roots, moisture content and moisture deficit in leaves, content of photosynthetic pigments and flavonoids, catalase activity.

It has been established that maize is the most resistant, while reddish and typhon are the most vulnerable to the salinity stress. Sainfoin and rape are resistant to salinity stress among the dicotyledonous crops. All studied mixes of siliceous minerals with organic admixtures favorably impact the growth of test plants: they stimulate the growth of herbs and root systems, the recovery of water regime, and the accumulation of protective compounds (flavonoids, anthocyans), intensify the biosynthesis of photosynthetic pigments in leaves, and enhance the catalase activity in tissues (Tables 1, 2). This testifies to the induction of respective antioxidant systems for the options with siliceous mixes. It is obviously that the favorable physiological action of studied mixes is caused by the intensification of biosynthesis of protective biomolecules and the stimulation of activity of protective fermentative antioxidant systems.

Under zero salinity, the highest growth and content of photosynthetic pigments are reported for maize and sainfoin in the case of mix no.1 (mineralized sapropel and siliceous minerals), no.2 (potassium silicate), no.3 (siliceous mineral blend); for oil reddish in the case of mixes no.1 and no.2; for rape and typhon in the case of mixes no.2 and no.4 (bog peat and siliceous minerals). At a salinity of 2—4% (NaCl solution) the highest growth and content of photosynthetic pigments are recorded for mixes no.2 and no.3. Mixes no.1 and no.3 effectively stimulate survival of sprouts sensitive to salinity stress.

Among the studied test plants oil reddish has showed the highest resistance to increasing acidity of growing medium. Maize is ranked second in

Table 1

Mixes on Morphometric Parameters for Various Salinity, $P < 0.01$

1	2	3	4	0	1	2	3	4	0	1	2	3	4
Root length, mm				Number of roots					Total root length, mm				
130	155	163	148	5,0	5.0	2.7	2.7	3.2	755	650	413	434	469
121	179	215	180	5,0	4.0	5.3	4.5	5.8	530	484	938	968	1035
132	208	225	233	5,0	4.0	5.0	4.6	5.7	755	528	1040	1035	1322
132	209	184	208	3,9	4.0	4.3	2.4	4.3	591	488	887	442	882
180	220	157	150	5,0	4.0	4.3	3.6	5.0	540	720	935	561	750

this regard. Sainfoin has proved itself to be the most sensitive to oxidative stress. All siliceous mixes favorably influence the growth of plants under oxidative stress: they stimulate the growth of herbs and root systems and intensify the biosynthesis of photosynthetic pigments in leaves (Table 3). Protective effect of mixes depends on *pH* of growing medium and species characteristics. For example, as a rule, maize, sainfoin, and rape have showed the highest growth in the case of mixes no.2 and no.4, while typhon in the case of mixes no.2 and no. 3, and reddish in the case of mixes no.1 and no.4 (in neutral growing medium) and in the case of mix no.2 at $pH = 4$.

Table 2

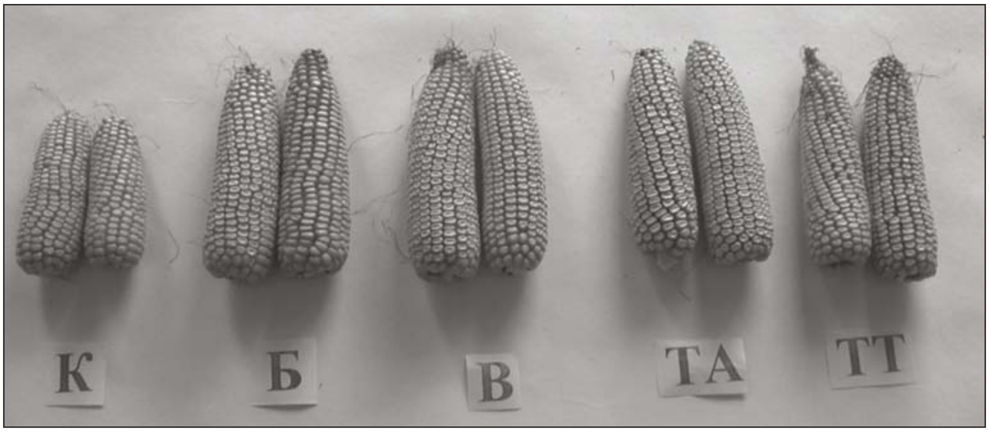
Effect of Siliceous Mineral Mixes on the Content of Flavonoids, the Catalase Activity in the Maize Leaves and the Content of Anthocyans in the Maize Roots for Various Salinity, $P < 0.01$

Salinity, %		Flavonoids, mg/g of dry substance					Anthocyans, optical density units, 1 g of leaf material in 1 ml solvent					Catalase activity, kmole H_2O_2 per 1 min. and 1 g raw leaf material				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Mix no.	0	2.4	2.7	2.6	3.1	3.2	0.43	0.5	0.65	1.56	1.66	7.2	7.47	9.49	12.4	19.9
	1	2.3	3.4	3.2	3.7	2.8	0.53	0.81	0.97	1.7	1.25	9.5	15.8	15.8	16.3	19.6
	2	2.5	3.3	3.1	3.7	3.3	0.94	0.87	1.05	1.93	1.7	10.3	9.96	12.5	14.4	18.9
	3	2.0	2.8	3.1	3.3	2.4	0.6	0.85	1.13	2.21	2.4	11.1	9.13	10.8	11.5	19.1
	4	2.8	3.8	4.1	3.1	2.7	0.5	0.55	0.91	1.89	1.37	18.6	19.1	18.3	18.1	19.0

Table 3

Effect of Siliceous Mineral Mixes on the Mass of Dry Material of Wild Turnip for Various pH of Growing Medium, $P < 0.01$

pH		Chlorophyll a				Chlorophyll b				Carotenoids				Mass of Dry Material, mg			
		4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7
Mix no	0	10	13	14	18	2.9	4.4	4.9	6.0	4.5	6	3.2	3.5	2.6	3.6	4.6	4.8
	1	15	16	16	18	5.7	4.7	5.2	6.6	3.4	5.1	3.9	3.6	3.7	4.6	4.9	4.7
	2	15	15	19	18	4.8	4.6	5.7	6.0	3.1	3.9	3.7	3.4	4.6	4.3	4.4	4.8
	3	11	13	13	19	3.4	3.9	4.6	6.0	4.0	3.5	3.6	3.0	4.4	4	4.1	4.8
	4	14	12	17	20	3.1	3.7	5.5	5.9	3.7	3.9	3.3	3.6	4.8	4.8	4.9	4.8



Effect of siliceous mixes (300 kg/ha) on yield of maize (field study): К — reference, Б — mix no.1, В — mix no.2, ТА — mix no.3, ТТ — mix no.4

The field studies were carried out at trial facilities of the Institute for Bioenergy Crops and Sugar Beets (black earth, *pH* within the range of 5.1—5.3 and humus, 2.0—2.1), area of 2.5 ha and of the Institute for Rice of the National Academy of Agrarian Science of Ukraine (medium alkalized, dark brown, *pH* = 6.5—6.8, humus, 1.4—1.9), area 2 ha.

The analysis of field studies has showed a favorable effect of siliceous minerals on yield rate of rice, maize, sugar beets, and soya, with highest yield reported for the mixes based on mineralized sapropel and potassium silicate. The optimal dosage of siliceous mixes with mineralized sapropel is 500 kg/ha; that for the other mixes is 300 kg/ha.

The analysis of harvest structural elements has showed that mineralized sapropel + siliceous minerals and potassium silicate + siliceous minerals + sapropel (5—10%) stimulate the creation of lateral shoots of rice, which favorably influences the total number of yielding stalks. In the same cases, a significant increase in grain weight per head has been reported. For instance, for the reference case, grain weight per head is 1.76 g, while in the case of mineralized sapropel + siliceous minerals (500 kg/ha) it amounts to 2.13 g. At the same time, it has been established that the siliceous minerals stimulate the growth intensification: the height of plants is 86 cm (reference) and 89—93 cm in the case of siliceous minerals.

Table 4

Performance of Farm Crops on the *Ksaverivka 2* Test Field of the Institute for Bioenergy Plants and Sugar Beets, in 2014

No.	Siliceous mineral mix, no.	Sugar beet			Corn maize		Soybean	
		Quart hybrid						
		Area, ha	Yield, tone/ha	Sugar degree, %	Area, ha	Yield, tone/ha	Area, ha	Yield, tone/ha
1	No.1	0.20	81.0	16.4	0.10	9.4	0.20	2.4
2	No.2	0.20	78.3	16.6	0.10	8.7	0.20	2.2
3	No.3	0.20	66.9	16.4	0.10	7.8	0.20	1.8
4	No.4	0.20	61.7	16.1	0.10	7.6	0.20	1.7
5	Reference	0.20	56.2	16.5	0.10	7.2	0.20	1.6

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The area of leaf surface is known to decrease substantially under salinity stress and so do the weight of wet vegetable weight, the seed yield, the photosynthesis, as well as the content of nitrate reductase, the chlorophyll biosynthesis, and the percentage of protein in seeds. And vice versa, the respiration, the activity of antioxidant ferments, the accumulation of proline, and the percentage of linolenic acid increase under salinity stress. Ascorbic acid has been proved to favorably influence nitrate reductase and chlorophyll synthesis *a* and *b*. If silicon is added, the area of leaf surface has been reported to increase, the raw vegetable weight grows, and so do the seed yield, the photosynthesis, the activity of ascorbate peroxidase and nitrate reductase, as well as the chlorophyll synthesis, however, the respiration decreases. Therefore, the silicon compounds are involved in protective mechanisms for neutralizing the salinity stress.

The studies have showed that the quantity and dynamics of content of ascorbic acid depend on the composition and dosage of siliceous mix. The most intensive synthesis of ascorbic acid in rice plants has been reported in the case of mix no.1 and mix no.3 at a dose of 300 mg. Their quantitative indices exceed those of reference plants 1.8—2.4 times. An increase by 34% and by 68% in the content of ascorbic acid has been recorded for the

Table 5

Growing Medium Redox under Various Crops in Model Tests, at Various Salinity, mV

NaCl, %	Option	Oil radish	Winter wild turnip	Maize	Sainfoin	Typhon turnip
0	Pure growing medium	240 ± 4.0	220 ± 3.8	250 ± 3.9	230 ± 4.2	236 ± 3.9
	Sapropel + minerals	286 ± 5.7	268 ± 5.4	291 ± 5.8	294 ± 5.9	295 ± 5.9
	K_2SiO_3, sapropel, minerals	263 ± 5.3	250 ± 5.0	283 ± 5.7	284 ± 5.7	274 ± 5.5
	Siliceous minerals	267 ± 5.4	240 ± 4.8	276 ± 5.5	263 ± 5.3	269 ± 5.4
	High-bog peat + rottenstone	257 ± 5.1	282 ± 5.6	300 ± 6.0	244 ± 4.9	255 ± 5.1
1	Pure growing medium	192 ± 3.8	180 ± 3.6	187 ± 3.7	197 ± 3.9	185 ± 3.7
	Sapropel + minerals	237 ± 4.7	223 ± 4.5	283 ± 5.7	257 ± 5.1	259 ± 5.2
	K_2SiO_3, sapropel, minerals	254 ± 5.1	229 ± 4.6	256 ± 5.1	230 ± 4.6	250 ± 5.0
	Siliceous minerals	215 ± 4.3	215 ± 4.3	265 ± 5.3	270 ± 5.4	260 ± 5.2
	High-bog peat + rottenstone	230 ± 4.6	245 ± 4.9	297 ± 5.9	294 ± 5.9	278 ± 5.6
2	Pure growing medium	185 ± 3.7	202 ± 4.0	195 ± 3.9	215 ± 4.3	175 ± 3.5
	Sapropel + minerals	230 ± 4.6	246 ± 4.9	214 ± 4.3	244 ± 4.9	260 ± 5.2
	K_2SiO_3, sapropel, minerals	289 ± 5.8	226 ± 4.5	262 ± 5.2	280 ± 5.6	246 ± 4.9
	Siliceous minerals	224 ± 4.5	213 ± 4.3	222 ± 4.4	274 ± 5.5	255 ± 5.1
	High-bog peat + rottenstone	235 ± 4.7	238 ± 4.8	279 ± 5.6	290 ± 5.8	285 ± 5.7
3	Pure growing medium	190 ± 3.8	195 ± 3.9	201 ± 4.0	200 ± 4.0	206 ± 4.1
	Sapropel + minerals	220 ± 4.4	240 ± 4.8	263 ± 5.3	260 ± 5.2	240 ± 4.8
	K_2SiO_3, sapropel, minerals	211 ± 4.2	226 ± 4.5	296 ± 5.9	280 ± 5.6	254 ± 5.1
	Siliceous minerals	206 ± 4.1	237 ± 4.7	300 ± 6.0	242 ± 4.8	238 ± 4.8
	High-bog peat + rottenstone	240 ± 4.8	250 ± 5.0	310 ± 6.2	257 ± 5.1	246 ± 4.9
4	Pure growing medium	222 ± 4.4	180 ± 3.6	207 ± 4.1	192 ± 3.8	194 ± 3.9
	Sapropel + minerals	261 ± 5.2	250 ± 5.0	295 ± 5.9	297 ± 5.9	255 ± 5.1
	K_2SiO_3, sapropel, minerals	245 ± 4.9	225 ± 4.5	300 ± 6.0	289 ± 5.8	244 ± 4.9
	Siliceous minerals	238 ± 4.8	218 ± 4.4	311 ± 6.2	212 ± 4.2	280 ± 5.6
	High-bog peat + rottenstone	270 ± 5.4	220 ± 4.6	305 ± 6.1	300 ± 6.2	273 ± 5.5

Standard sugar beet leaves in the case of mix no.1, and for the *Quart* sugar beet in the case of mix no.2, respectively. An increase in ascorbic acid synthesis (24—57%) and sugar synthesis (21—98%) as compared with the reference plants has been established for soya as well. Maize has sho-

Table 6

Number of Microorganisms of Basic Taxonomic and Eco-Trophic Groups of Winter Wheat Rhizosphere on Acidic Soils of *Salivonky* Test Farm, Kaharlyk District, 2014

Test option	Number of microorganisms (CFU per 1 g of completely dry soil)				Mineralization-immobilization factor	Organic substance transformation factor	Nitrogen-fixing microorganisms, %
	Micromycetes, $\times 10^3$	Actinomyces, $\times 10^4$	Ammonifiers, $\times 10^4$	Oligonitrophils, $\times 10^4$			
Reference	27.6 ± 3.5	0.2 ± 0.07	10.2 ± 0.6	5.0 ± 0.4	0.5	30.47	100
High-bog peat, siliceous minerals	25.6 ± 1.4	0.6 ± 0.007	7.2 ± 0.7	6.2 ± 0.2	0.9	14.9	100
Siliceous minerals	53.9 ± 0.7	0.4 ± 0.007	5.0 ± 0.6	5.3 ± 0.4	1.1	9.4	100
Potassium silicate, siliceous minerals, sapropel	51.3 ± 5.0	0.2 ± 0.008	7.1 ± 0.5	4.9 ± 0.4	0.7	17.1	100
Minerlized sapropel, siliceous minerals	48.7 ± 5.1	0.3 ± 0.001	7.7 ± 0.4	5.7 ± 0.1	0.7	19.1.	95

*CFU — colony forming unit

Table 7

Comparison of Nitrification Inhibitor Effects Depending on the Content of Organic Matter and *pH* of Growing Medium*

Test	Growing medium	*pH*	Organic matter, %	Content of nitrate nitrogen, mg/kg		
				Exposure, days		
				15	30	45
Winter wheat						
Reference	Sand	7.2	0.03	115.7	193.6	298.1
	Soil mix	6.2	7.5	146.9	235.8	334.2
Nitrapyrin, 200mg/200g growing medium	Sand	7.2	0.03	97.5	83.9	92.4
	Soil mix	6.2	7.5	101.7	88.3	95.6
Mix of rottenstone and analcime, 200mg/200g growing medium	Sand	7.2	0.03	71.3	64.9	61.7
	Soil mix	6.2	7.5	73.8	66.1	64.3
Maize						
Reference	Sand	7.2	0.03	99.3	168.4	255.8
	Soil mix	6.2	7.5	125.7	191.0	287.1
Nitrapyrin, 200mg/200g growing medium	Sand	7.2	0.03	81.2	73.7	77.6
	Soil mix	6.2	7.5	87.9	76.4	82.3
Mix of rottenstone and analcime, 200mg/200g growing medium	Sand	7.2	0.03	52.4	43.9	42.5
	Soil mix	6.2	7.5	54.3	45.1	43.2

Note. * — 50 ml of 0.5% carbamide solution per 200 g of growing medium sis added weekly wed a growth in the content of ascorbic acid by 43% and in the total sugar content by 31%, in the case of siliceous mix no.1. The intensification of ascorbic acid synthesis in the leaves when siliceous mixes are added testifies to the enhancement of protective functions under stressful conditions, including the salinity and the oxidative stresses of soils.

The siliceous mixes favorably influence the content of sugar in the vegetable tissues, which entail favorable changes in photosynthesis and productivity of the crops.

Productivity of all studied crops has been established to increase if the siliceous mixes are added (Table 4). In this case, increase in yield does not impaired the quality of products (does not lead to dropping sugar content in the crops under review. The data obtained have confirmed the effectiveness of the mixes used and their favorable impact not only on the vegetation processes, but also on the seed yield (see Figure).

ROLE OF SILICEOUS MIXES IN THE STRUCTURAL AND FUNCTIONAL ORGANIZATION OF SOIL ECOSYSTEM UNDER SALINITY AND OXIDATIVE STRESSES

The results obtained by the method of direct biological testing of model growing medium [4] have showed that for 1% NaCl, the phytotoxicity of soil substitutes is equal to 10—29% as compared with the reference sample (pure neutral growing medium); for 2% NaCl, it amounts to 18—59%; for 3% NaCl, it reaches 33—59%; for 4% NaCl, it makes up 32—76%. If the siliceous mixes are added, the figures decrease 1.1—3.9 times. For certain combinations of NaCl dosage and mix content, phytotoxicity disappears and growth stimulation is reported.

Table 8

Calcium Content in the Soil with Siliceous Minerals Added, Under Oxidative and Salinity Stresses, mg/l (1H HCl)

Test	1st selection of samples (July)					2nd selection of samples (September)				
	Crops									
	Sugar beet		Maize	Soya	Rice	Sugar beet		Maize	Soya	Rice
	Standard	Quart				Standard	Quart			
Reference	2998.8	4498.2	4165.0	3631.8	1166.2	4487.5	4998.7	4165.0	4998.0	2332.7
Mix no.1	3831.8	5331.2	4998.0	4165.0	3831.8	5831.0	5497.8	6330.2	5731.9	2499.5
Mix no.2	3998.4	5348.4	4664.8	4498.2	3498.6	6664.0	7163.8	6964.5	5811.6	2511.7
Mix no.3	4331.6	5997.6	5331.2	6330.8	4165.0	6830.7	7497.0	7497.5	5984.5	2998.8
Mix no.4	3989.6	4664.8	4573.6	3869.7	2998.8	4998.1	5399.7	5999.3	5331.7	2483.6

Table 9

Aluminum Content in the Plants, with Siliceous Mixes Added, mg/kg of Dry Vegetation Mass

Test	Sugar Beet		Maize	Soya	Rice
	Standard	Quart			
Reference	639.6	404.0	288.2	853.8	501.6
Mix no.1	248.5	270.3	49.24	551.2	300.9
Mix no.2	249.7	220.4	67.99	580.4	239.8
Mix no.3	364.8	292.8	41.21	468.1	398.1
Mix no.4	237.5	311.7	144.6	657.4	257.1

The phytotoxicity of growing medium has been established to decrease under high salinity (NaCl concentration of 3 and 4%) in the case of application of siliceous mixes, mainly, for winter rape (2.1—3.9 times) and sainfoin (2.0—2.3 times). Under low pH (4—5) the most significant decrease in phytotoxicity of growing medium is reported for oilseed reddish (1.2—2.6 times or complete disappearance) and maize (1.5—2.4). The use of siliceous minerals and bog peat in combination with rotten stone is the most effective for reducing phytotoxicity in the case of both the salinity and the oxidative stresses.

In the case of oxidative stress, the alelopatic activity of growing medium without mixes added changes as follows: growth of biotest is inhibited by 49% at $pH = 4$, by 64% at $pH = 5$, by 28% at $pH = 6$ as compared with the reference sample (growing medium without mixes added at $pH = 7$). The use of mixes causes reducing the phytotoxicity and growing the biotest 1.1—1.3 times, at $pH = 6$; 1.8—2.4 times, at $pH = 50$; 1.5—1.7 times, at $pH = 4$. The mixes based on potassium silicate and peat (no. 2 and no. 4) are the most effective for reducing phytotoxicity of growing medium at high pH ($pH = 4$). At $pH = 5$—6, phytotoxicity of growing medium decreases mainly if mixes no.2 and no.3; at $pH = 7$, the biotest is reported to grow (by 9—20% as compared with the reference sample) when the abovementioned mixes are added.

The biochemical activity of the growing medium was estimated by redox potential that is closely associated with transformation of organic matter. Under salinity, the use of siliceous mixes has been established to increase redox 1.1—1.6 times, (Table 5), as they optimize the oxidation and reduction processes in the growing medium, which improves its properties for optimizing plant growth under both salinity and oxidative stresses.

As of today, there is no information on electric conductivity of soils for the plants cultivated at various NaCl concentration. For the first time, it has been established that the presence of siliceous mixes in the growing medium stimulates the accumulation of Na and Cl by phyto-ameliorant plants. Specific selectivity of plants with respect to distribution of these elements depending on mix composition has been found. Maize and sainfoin have been established to be the most resistant to salinity.

The field studies have showed that under conditions of secondary salinity, the soil toxicity for rice decreases if potassium silicate at a dosage of 500 kg/ha is added. This mix is also effective under conditions of oxidative stress for sugar beets, soya, maize, and wheat. Positive result has been obtained for the mix containing mineralized sapropel, for soya and maize. The use of siliceous mixes stimulates raising redox under secondary salinity for rice and under oxidative stress for sugar beet, soya, maize, and wheat, which leads to weakening of the reduction processes and optimization of conditions for nutrition and humification. The content of free phenol substances in the soil has been reported to decrease for rice, under salinity, and for sugar beet, soya, maize, and wheat, under oxidative stress, in the presence of siliceous mixes, which means that the mixes are actively involved in humification.

Microbiota is an important factor for agro-ecosystems, which influences soil fertility and plant growth. Microorganisms are the largest and the most diversified in terms of composition component of the rhizosphere. The soil microorganisms perform different ecological functions, with the most important ones being to ensure certain stages of biogenic element circulation and to support homeostasis of biogeocoenosis [5].

The use of siliceous mixes firstly leads to imbalance of microbial coenosis and further, to stabilization and intensification of microorganism activity. Functional restructuring of microbial coenosis is caused by the presence of siliceous mixes. It manifests itself by changing not only the quantities of certain eco-trophic groups of soil microorganisms, but also the direction of microbial processes in the soil (Table 6). The most sensitive reaction of soil microorganisms on the siliceous mixes has been reported for soya and maize, especially in the case of mixes no.1 and no.2.

As a result of the studies, the involvement of silicon compounds in nitrification inhibition has been established for the first time. This enables to use nitrogenous fertilizers more effectively. The comparative analysis of duration of effect of nitrification inhibitors has showed a high persistency of siliceous minerals as compared with widely used nitrapyrin (Table 7). Especially interesting are the microbiologic studies of growing medium with siliceous minerals added, which have been carried out for the first time. The quantity of nitrifiers has been established to gradually decrease, which testifies to a prolonged action of silicon compounds as inhibitors of nitrification in the soil.

It has been proved that the minerals are friendly to the soil microbiota as the total quantity of microorganisms in the soil remains high and no sharp fluctuations of ammonifiers, nitrifiers, and denitrifiers are reported.

The use of siliceous mixes stimulates reducing soil phytotoxicity, increasing potassium concentration in the soil and growing potassium content in the plants (Table 8). The opposite dependence has been reported for the magnesium distribution in the soil: under alkalization, the magnesium content in the plants increases, while under salinity, its concentration decreases. The favorable effect of siliceous mixes on the penetration of potassium cations to the plants, which has a favorable impact on thermodynamic absorption of microelement cations by root systems has been proved. Under alkalization, the siliceous mixes stimulate growing the content of zinc in the plants, while under secondary salinity, the manganese content increases. For the first time, the siliceous mixes has been established to inhibit penetration of heavy metals to the plants (Table 9).

According to estimates of international experts, the phosphorous ore deposits will be exhausted in 85 years, provided the current rate of extraction is kept. The given studies have showed that in order to address this problem caused by the lack of raw material for producing phosphorous fertilizers it is advisable to use the siliceous mixes which stimulate increase in the content of mobile forms of phosphorus due to releasing phosphates from the forms that are low accessible for the plants.

The studies have showed an important role of siliceous mixes for raising the adaptability of plants to both acidic and saline soils, which is ensured by increase in concentration of macro- and microelements in the plant tissues. The siliceous compounds favorably effect the optimization of phosphorus supply to the plants due to increase in phosphates of the 1st and 2nd groups accessible for the vegetable organisms. The silicon contribution to the structural and functional organization of biogeocoenosis has been showed.

The effectiveness of siliceous minerals has been confirmed on rice fields in PRC and UAE.

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ВПРОВАДЖЕННЯ НОВІТНЬОЇ ТЕХНОЛОГІЇ ХІМІЧНОЇ ТА ФІТОМЕЛІОРАЦІЇ КИСЛИХ І ЗАСОЛЕННИХ ГРУНТІВ

Запропоновано методи впровадження новітньої технології меліорації кислих і засолених ґрунтів, яка базується на комплексному використанні кремнієвмісних сумішей за сумісного вирощування злакових, бобових і хрестоцвітих видів рослин. Розроблено технологічний регламент для застосування хімічних і фітомеліорантів у різних ґрунтово-кліматичних зонах України. Визначено кремнієвмісні суміші з високим меліоративним потенціалом та оптимальні дози їх застосування. Проведено комплексне вивчення хімічних і фітомеліорантів та визначено їх роль у стимуляції розвитку агрономічно-корисної мікробіоти. Покращено агрофізичні, агрохімічні, біологічні показники ґрунту та зменшено токсичність і ґрунтовтому на фоні внесення кремнієвмісних сумішей. Вдосконалено структуру сівозмін.

Ключові слова: кислі та засолені ґрунти, хімічна та фітомеліорація, кремнієвмісні суміші, сільськогосподарські культури, адаптивний потенціал.

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ВНЕДРЕНИЕ НОВЕЙШЕЙ ТЕХНОЛОГИИ ХИМИЧЕСКОЙ И ФИТОМЕЛИОРАЦИИ КИСЛЫХ И ЗАСОЛЕННЫХ ПОЧВ

Предложены методы внедрения новейшей технологии мелиорации кислых и засоленных почв, основанной на комплексном использовании кремнийсодержащих смесей при совместном выращивании злаковых, бобовых и крестоцветных видов растений. Разработан технологический регламент для применения химических и фитомелиорантов в различных почвенно-климатических зонах Украины. Определены кремнийсодержащие смеси с высоким мелиоративным потенциалом и оптимальные дозы их применения. Проведено комплексное изучение химических и фитомелиорантов, определены их роль в стимуляции развития агрономически полезной микробиоты. Улучшены агрофизические, агрохимические, биологические показатели почвы и снижены токсичность и почвоутомление на фоне внесения кремнийсодержащих смесей. Усовершенствована структура севооборотов.

Ключевые слова: кислые и засоленные почвы, химическая и фитомелиорация, кремнийсодержащие смеси, сельскохозяйственные культуры, адаптивный потенциал.

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