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THE ROLE OF SILICON IN IMPROVING THE BIOTROPHIC CHARACTERISTICS OF THE SOIL

Zaimenko Natalia[1,*] https://orcid.org/0000-0003-2379-1223,
Rakhmetov Dzhamal [1] https://orcid.org/0000-0001-7260-3263,
Pavliuchenko Nataliia [1] https://orcid.org/0000-0001-8934-7163,
Didyk Nataliya [1] https://orcid.org/0000-0001-8448-7490,
Kharytonova Iryna [1] https://orcid.org/0000-0001-9540-5278,
Yunosheva Olena [1] https://orcid.org/0000-0003-1349-7733,
Zakrasov Oleksandr [1] https://orcid.org/0009-0005-0753-5547,
Dziuba Oksana [1] https://orcid.org/0000-0002-8298-9822,
Slyusarenko Olexandr [2] https://orcid.org/0000-0001-6287-3243
[1] M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, Kyiv,
[2] National Scientific Center "V. Ye. Tairov Institute of Viticulture and Winemaking" of the National Academy of Agrarian Sciences of Ukraine, Tairove, Odessa region, Ukraine
* e-mail: zaimenkoNV@ukr.net

Summary. The role of siliceous fertilizer (based on silt deposits and siliceous minerals) in improving the biotrophic characteristics of the soil and the physiological state of oil crops were clarified. The positive influence of silicon on the microbiological activity and agrochemical properties of the soil, the allelopathic potential of the root environment and the adaptability of false flax (or camelina), Ethiopian mustard and spring rapeseed plants under stressful environmental conditions were established.

Keywords: siliceous fertilizer, soil microorganisms, soil organic matter, laccase, allelopathic activity, secondary metabolites, oil crops.

Introduction

Changing climatic conditions, the spread of diseases and pests pose a major threat to the productivity of agricultural crops worldwide. The rhizosphere zone of plants contains beneficial microorganisms that help plants withstand stressful conditions and promote nutrient absorption. It is known that the interaction of plants and microbes improves the agrophysical condition of the soil, increases its fertility and water-holding capacity [12]. Recently, silicon compounds have been used to optimize the soil-plant-microorganism system, which have a wide range of effects on soil processes, physiological parameters of plants, and microbiocenosis [2, 15, 16]. The study of biotrophic interactions is promising for the development of effective and environmentally safe means of plant protection and fertilizers. At the same time, there is considerable scientific and practical interest in finding ways to increase the adaptability and productivity of valuable oil crops, in particular from the *Brassicaceae* family, which have a powerful allelopathic potential [4, 13].

The purpose of the work is to analyze the effect of siliceous fertilizer on the agrochemical, microbiological, allelopathic characteristics of the soil and the physiological state of oil plants of the *Brassicaceae* family.

Materials and methods

Plant and soil samples were collected at experimental plots of the M.M. Gryshko National Botanical Garden. Siliceous fertilizer (based on silt deposits and siliceous minerals) was applied to

the soil at the rate of 300 kg/ha. The soil was sampled at a depth of 0-20 cm. The soil outside the experimental plots served as a control.

The objects of the study were plants of false flax (or camelina), (*Camelina sativa* (L.) Crantz f. *annua*, cv. Peremoha), Ethiopian mustard (*Brassica carinata* A. Braun) and spring rapeseed (*Brassica napus* f. *annua* D.S., cv. s. Rimal). Plant and soil samples were analyzed during the growing season according to development phases: juvenile, budding-flowering and fruiting.

Allelopathic soil analysis was carried out by the method of direct biotesting using amaranth seedlings (*Amaranthus paniculatus* L.) as test objects [9]. The content of labile organic matter and soluble carbonates was determined in soil samples [9, 10]. Soil laccase activity was determined spectrophotometrically according to P. Baldrian [3]. Microbiological studies were carried out by sowing soil suspensions in appropriate dilutions on selective agarized nutrient media [9]. The directionality of microbiological processes was assessed by the coefficient of mineralization-immobilization of soil organic matter [9]. The physiological state of the plants was assessed by the concentration of secondary metabolites in the leaves. The content of flavonoids and anthocyanins was determined spectrophotometrically [6, 11]. The level of tannins was analyzed according to M. Mardar et al. [8].

Results and discussions

The use of siliceous fertilizer had a positive effect on the content of labile organic matter and laccase activity (Figures 1, 2).

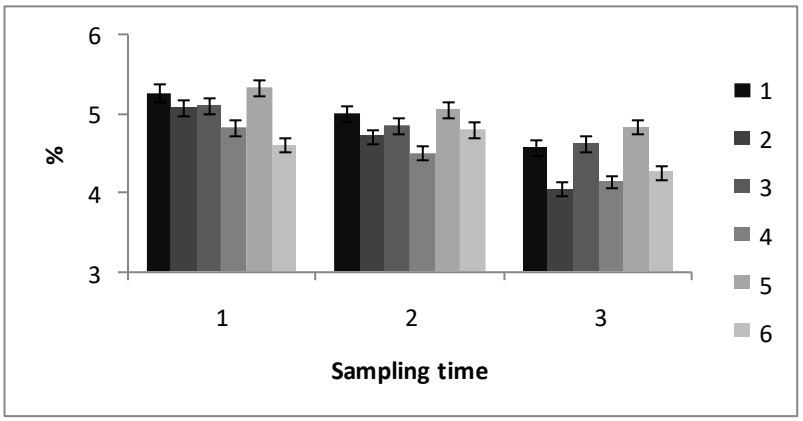


Figure 1. Effect of siliceous fertilizer on the content of labile soil organic matter, %:
1 – camelina + silicon; 2 – camelina, control; 3 – mustard + silicon; 4 – mustard, control; 5 – rapeseed + silicon; 6 – rapeseed, control. Sampling time: 1 – juvenile phase of development; 2 – budding-flowering phase; 3 – fruiting phase. Error bars indicate SD (standard deviation of the mean).

It should be noted that the highest level of organic matter was recorded in the research option with siliceous fertilizer for rapeseed, which, in our opinion, is associated with the highest laccase activity and carbon deposition as a result of nitrogen fixation. In addition, the control plot of the soil, on which there were no experimental plants, was distinguished by very low indicators, in particular: the content of the labile organic matter during the growing season of the plants was in the range of 2.1-3.1%, and the activity of laccase, respectively, was 85.67-92.34 mU/g of soil.

The maximum content of organic matter was observed at the beginning of the growing season of the plants. These results are consistent with the data of laccase determination. Subsequently, there is a gradual decrease in the number of labile organic matter due to the formation of stable forms, which is evidenced by both a decrease in laccase activity and a decrease in the concentration of HCO^3 (Figures 2, 3). The increase in the level of HCO^3 in the phase of budding – flowering (summer) is explained by the increase in air temperature and the activation of the development of soil microorganisms.

The assessment of the number of taxonomic and functional groups of microorganisms in the soil of oil crops with the application of siliceous fertilizer showed an increase in the number of micromycetes that participate in the synthesis of laccase and the destruction of lignin (Figure 4).

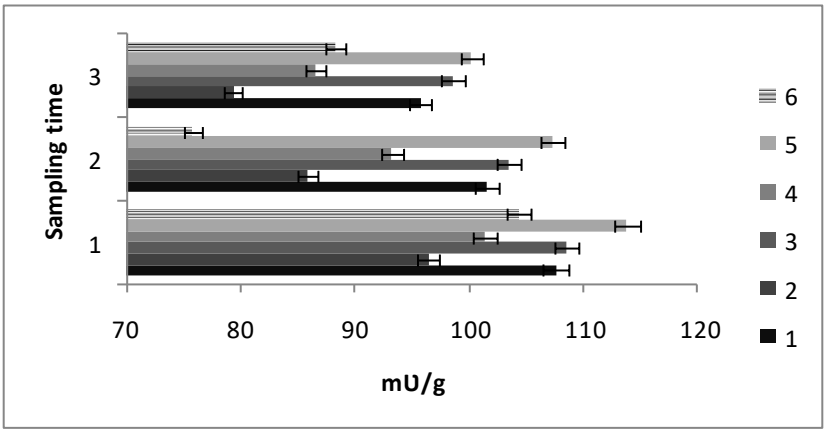


Figure 2. Effect of siliceous fertilizer on the soil laccase activity, mU/g of soil: 1 – camelina + silicon; 2 – camelina, control; 3 – mustard + silicon; 4 – mustard, control; 5 – rapeseed + silicon; 6 – rapeseed, control. Sampling time: 1 – juvenile phase of development; 2 – budding-flowering phase; 3 – fruiting phase. Error bars indicate SD (standard deviation of the mean).

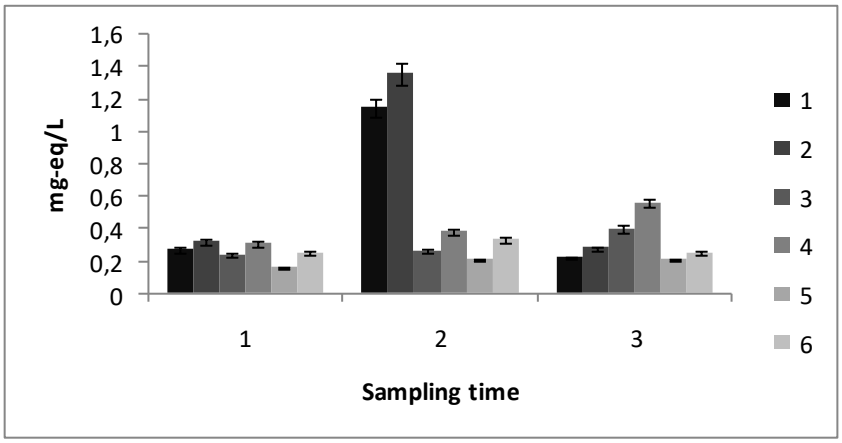


Figure 3. Effect of siliceous fertilizer on concentration HCO_3 in the soil under the oil crops, mg-eq/L: 1 – camelina + silicon; 2 – camelina, control; 3 – mustard + silicon; 4 – mustard, control; 5 – rapeseed + silicon; 6 – rapeseed, control. Sampling time: 1 – juvenile phase of development; 2 – budding-flowering phase; 3 – fruiting phase. Error bars indicate SD (standard deviation of the mean).

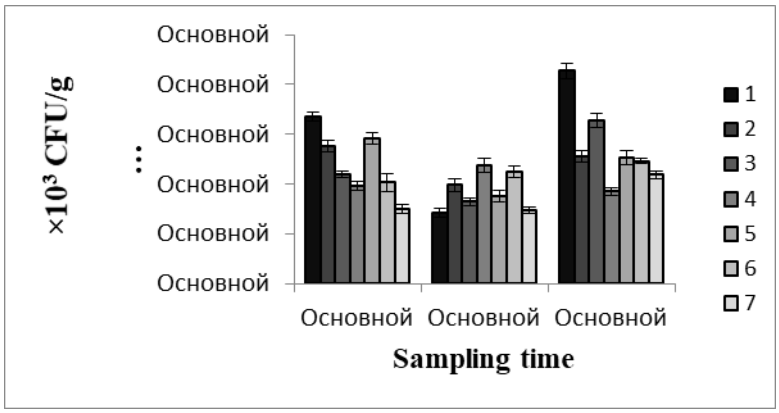


Figure 4. Effect of siliceous fertilizer on the number of micromycetes in the soil under the oil crops, ×10^3 CFU/g of dry soil: 1 – camelina + silicon; 2 – camelina, control; 3 – mustard + silicon; 4 – mustard, control; 5 – rapeseed + silicon; 6 – rapeseed, control, 7 – control soil (soil plot without plants). Sampling time: 1 – juvenile phase of development; 2 – budding-flowering phase; 3 – fruiting phase. Error bars indicate SD (standard deviation of the mean).

Note: CFU – colony-forming unit

The ratio of individual indicators of the number of trophic groups of microorganisms allows determining the direction of microbiological processes of mineralization-immobilization of soil organic matter. The values of the mineralization-immobilization coefficients in the test samples of all experimental crops during the growing season were lower than the control value, which indicates the predominance of organic matter accumulation processes (Table 1). Mineralization processes were most active in soil samples from camelina (juvenile and fruiting phase) and rapeseed (budding-flowering phase) in the absence of silicon.

Table 1

Directionality of microbiological processes of mineralization-immobilization of soil organic matter

Oil crops	Research option	Coefficient of mineralization-immobilization		
		Juvenile phase of development	Budding-flowering phase	Fruiting phase
Camelina	Siliceous fertilizer	0.9	0.69	1.2
Camelina	Control	1.3	1.0	1.6
Mustard	Siliceous fertilizer	0.5	0.8	1.2
Mustard	Control	0.8	1.2	1.3
Rapeseed	Siliceous fertilizer	0.9	1.2	0.8
Rapeseed	Control	1.2	1.5	0.8
Control	Soil without plants	0.9	1.5	0.9

The accumulation of organic matter prevailed in the experimental research options, the most under mustard and camelina, which indicates the positive effect of siliceous fertilizer application.

The analysis of the soil allelopathic activity showed a high sensitivity of the acceptor plants to silicon, which was manifested in the intensification of growth processes during all stages of development of the studied crops (Figure 5). At the same time, the greatest decrease in allelopathic activity in the presence of silicon was found in the phases of budding-flowering (by 27%) and fruiting (by 21%) for mustard, as well as for rapeseed at the end of the growing season (by 25%).

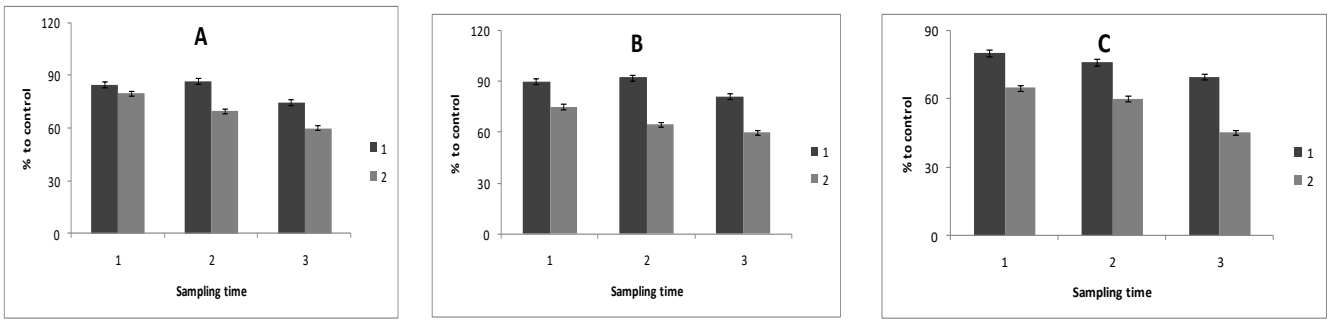


Figure 5. Allelopathic activity of soil under camelina (A), mustard (B) and rapeseed (C) (biotest – root growth of *Amaranthus paniculatus*), % to control (soil plot without plants): 1. – soil + silicon; 2. – soil without silicon. Sampling time: 1 – juvenile phase of development; 2 – budding-flowering phase; 3 – fruiting phase. Error bars indicate SD (standard deviation of the mean).

The improvement of agrochemical, allelopathic and microbiological characteristics of the soil with siliceous fertilizer also had a positive effect on the physiological state of the plants. Secondary metabolites, in particular flavonoids and anthocyanins, are known stress markers, the biosynthesis of which increases in response to adverse environmental conditions [1, 5, 14]. Thus, in the budding-flowering phase (summer season), under the influence of high temperatures and drought, an increase in the content of flavonoids and anthocyanins in leaves was observed (Table 2). This indicates the stress state in the plants. At the same time, the content of flavonoids and anthocyanins in the leaves significantly decreased when siliceous fertilizer was applied.

Table 2

The effect of siliceous fertilizer on the content of secondary metabolites in the leaves of oil crops (mean ± SD)

Oil crops	No	Flavonoids, mg/g of fresh substance		Anthocyanins, %		Tannins, %	
		Control	Silicon	Control	Silicon	Control	Silicon
Camelina	1	8.58±0.32	8.25±0.45	0.11±0.01	0.04±0.01	27.2±1.1	8.0±0.6
	2	11.56±0.24	8.76±0.22	0.13±0.01	0.07±0.01	16.2±0.8	12.4±0.4
Mustard	1	13.86±0.39	12.80±0.32	0.07±0.01	0.05±0.01	11.4±0.9	9.3±0.7
	2	17.64±0.35	15.27±0.22	0.18±0.01	0.08±0.01	8.3±0.6	7.2±0.8
	3	7.99±0.24	5.64±0.31	0.13±0.01	0.06±0.01	7.3±0.5	6.4±0.7
Rapeseed	1	13.90±0.22	13.25±0.44	0.09±0.01	0.04±0.01	17.4±0.8	11.1±0.6
	2	17.83±0.32	18.29±0.52	0.11±0.01	0.06±0.01	15.3±0.9	11.2±0.8

Note: 1 – juvenile phase of development; 2 – budding-flowering phase; 3 – fruiting phase.

Tannins as products of secondary synthesis are also involved in the protective reactions of plants to biotic and abiotic stresses [14]. In addition, tannins are involved in the regulation of plant growth and development processes [7]. Application of siliceous fertilizer significantly reduced the content of tannins in the leaves, which indicates a reducing the intensity of stress and a more active growth processes in the experimental plants (Table 2).

Conclusions

Therefore, the microbiological monitoring of the soil under the oil crops showed that the processes of transformation of organic matter with the application of siliceous fertilizer were more aimed at its accumulation compared to the control options. The positive effect of silicon on the allelopathic potential of the root environment of camelina, mustard and rapeseed during the growing season was proved. The siliceous fertilizer contributed to a decrease in the content of secondary metabolites (flavonoids, anthocyanins, tannins) in the leaves of the oil crops, which indicates a reduction of the stress load on plants under adverse environmental conditions (high temperature, drought).

In general, the application of siliceous fertilizer is effective and promising for improving the agrochemical, microbiological, allelopathic characteristics of the soil and the physiological state of plants.

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