

The results of chemical reclamation of the soil component of natural and seeded meadows in the Non-Black Soil Zone of the Russian Federation

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Abstract. The reclamation role of the preparation Kovelos in relation to elements of the heavy metal group – copper and zinc - has been proven: a decrease in their gross concentration when applying a silicon-containing nanopreparation at a dose of 120 kg/ha is statistically significant. Thus, soil grassing in combination with the introduction of a silicon-containing preparation is an effective method of land reclamation in aerotechnogenic pollution areas. It was found that during the four-year period of meliorant application, OCC values in soils grassed with natural and seeded vegetation increased for 3 and 4 years of observation. The differences in the OCC fixation differ unreliably with the variants without the addition of nanosilicon, nevertheless, OCC reserves increase significantly. The range of OCC accumulation as a result of long-term use of chemical meliorant is as follows: caper euphorbia + oats > common timothy > cow clover > koeleria-red fescue > two-source > cow parsnip-foxtail. The use of synthetic amorphous silicon dioxide leads to cheaper reclamation methods, reduced labor and energy costs, the use of an affordable and cheap drug, and the action complexity.

1 Introduction

Measures for soil reclamation and rehabilitation are diverse and the search for the most ergonomic and environmentally beneficial ones involve large-scale work, including on agrochemistry with the use of chemical meliorants. In the Non-Black Soil Zone of the Russian Federation, promising for improving soil chemistry and metabolic processes is synthetic amorphous silicon dioxide (trademark Kovelos-Rost), used for the rehabilitation of meadow soils when contaminated with elements of the heavy metal group (HM), as well as to improve the forage indicators of grass stands of natural and seeded meadows: the content of ascorbic acid, crude protein, carotene, the content of fiber, crude ash. Kovelos nanopreparation is a light micronized (particle size depending on the brand from 6 to 40 microns) white powder without taste and odor, has pronounced sorption properties, with a specific surface area of 350-400 m² per 1 gram, with an oil capacity of 300-340 g/100 g.

Nanoporous amorphous silicon dioxide, introduced in powder form, is well converted into polysilicon acids, which determine biological processes, as well as chemical and

physical processes occurring in the soil. The paper presents the results of application in agrotechnologies as regulators of biochemical and metabolic processes in plant biomass and soil, capable of mobilizing productive, protective systems of plant organisms, optimization of agrochemical and agrophysical indicators of soils [11, 14].

Silicon fertilizers determine the production and growth processes in meadow plants, the content of gross and mobile forms of the biophilic and cyclic element silicon is one of the limiting indicators for plant development. Due to the ion-exchange ability, nanoporous silicon-containing fertilizers increase the capacity of cation exchange, the absorption capacity of soils, and homeostatize soil acidity. Despite the significant distribution of silicon in the Earth's crust and the bioinert body – soil, producers absorb only silicic acid monomers [1, 2, 5-7]. The study of the effect of synthetic nanoporous silicon-containing fertilizers on the production processes of meadow grass will reduce the cost of measures to improve natural and seeded meadows, improve the quality of finished products, and develop sustainable agricultural production to reproduce the feed base for livestock in conditions of import substitution. Interest in the use of silicon-containing fertilizers is also associated with the environmental safety of preparations, the possibility of replenishing silicon reserves in the soil and the relatively inexpensive method of chemical reclamation of meadow soils and anthropogenic transformed substrates that have lost their natural fertility and rehabilitation of contaminated soils [2, 10].

The purpose of the work is to present the results of experimental studies on the chemical rehabilitation of soils of meadows of different origin for the Non-Black Soil Zone of the Russian Federation within the Bryansk region.

2 Materials and Methods

The effect of the silicon-containing preparation "Kovelos-Rost" (DA) was studied in vivo on the basis of a long-term experiment with natural meadows (Bryansk, Rognedinsky district of the Bryansk region), seeded meadows (Zhiryatinsky, Karachevsky district of the Bryansk region).

The main indicators of soils in meadows are: sod-gleic sandy loam soils, pH 4.6-5.3, P_2O_5 – 582-617 mg/kg. To determine the results of chemical reclamation, experiments were conducted on sowing plots with a size of 50 m², an accounting plot with an area of 20 m² in accordance with the recommendations of the "Methodology of experiments on hayfields and pastures" [8]. Meliorant – amorphous silicon dioxide (DS) – was applied in the form of top dressing with a full dose in one step, as well as phosphorus (simple granulated superphosphate) and potassium (potassium chloride) fertilizers – $P_{40}K_{60}$; nitrogen fertilizers were not applied to legume-cereal seed meadows. In natural meadows on trial sites, DS was applied by spraying in the form of top dressing also in one step, in the spring period at the beginning of the growing season; during a 4-year period.

The number of mowing for perennial crops is two: in the first decade of June, in the fourth decade of August, for annual sowing – the third decade of July [8].

In natural meadows, trial sites (PP) were selected with herbage formed in various environmental conditions according to moisture content, soil acidity, nitrogen content (determined by the scales of G. Ellenberg) [13]. Communities of the association *Phalaridetum arundinaceae* Libbert 1931 (B – soil moisture – 7.9 – moist habitats, K – soil acidity – 6.3 – slightly acidic, N – nitrogen supply – 5.8 – medium nitrogen supply); communities of the association *Heracleo sibirici-Alopecuretum pratensis* Bulokhov 2001 (B – 4.9 – fresh habitats, K – 5.4 moderately acidic, N – 8.8 – nitrogen-rich); communities of the *Koelerio delavignei-Festucetum rubrae* Bulokhov 2001 association (B – 4.6 – moderately dry habitats, K – 6.1 moderately acidic, N – 4.2 – moderately nitrogen-poor) were considered.

3 Results and Discussion

In the communities *of the Phalaridetum arundinaceae Libbert 1931 association*, the projective coverage is 98%, when overwetted habitats are transformed into a sedge type of meadows, floral saturation is 5-8 species per 100 m². In the communities of cow parsnip-foxtail, the highest floral saturation is 23-32 species per 100 m², and various grasses are well developed. The communities of the *Koelerio delavignei-Festucetum rubrae* Bulokhov 2001 association are widespread, with an average floral composition of 12-18 species per 100 m², a group of mixed grasses with a dominance of xeromesophytic cereals is represented.

The dominants of the sown meadows are represented by red clover and common timothy, caper euphorbia, and oat: the age of the perennial meadow is 3 years.

Pollutants in the form of aqueous solutions of ZnCl₂ and CuCl₂ salts were previously applied to the PP soil at the rate of 0.3 g and 0.9 g of metal ions per 1 kg of soil.

The organic matter was determined in accordance with GOST 26213-84, the pH of the salt extract was ionometrically (GOST 24483-85), mobile humic substances were extracted with 0.1 M Na₄P₂O₇ solution at a dilution of 1:15, mobile OCC was extracted with 0.1 n sodium hydroxide solution, determining the carbon content by the Tyurin method [12].

The determination of the gross content of HM in soil and plant samples was performed according to the "Method of measuring the mass fraction of metals and metal oxides in powdered soil samples by X-ray fluorescence analysis. M049-P/04", using the Spectroscan Max instrument TU 4276-001-23124704-2001 in powder samples [9]. The values given in GN 2.1.7.2041-06 and GN 2.1.2042-06 were used as approximate permissible concentrations (APC) of HM in soils.

The preparation Kovelos was prepared for experiments in different concentrations. Similar concentrations of the preparation Kovelos-Rost were introduced into the soil of the experimental plots. Statistical data processing was carried out in the Microsoft Office Excel 2010 package, using generally accepted statistical parameters [4].

The results of studies of the effect of amorphous silicon dioxide on soil chemistry are discussed below (Fig. 1-8).

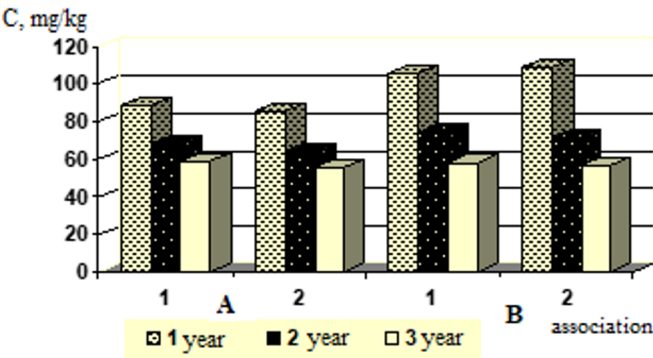


Fig. 1. Dynamics of the gross copper content (mg/kg) when applying a synthetic silicon-containing preparation (50 kg/ha) under perennial seeded meadows over a three-year observation period.

Note. Communities of seeded meadows: 1 dominant cow clover, 2 dominant common timothy. Concentrations of copper (mg/kg): A – in the variant 0.3 g per 1 m², B – in the variant 0.9 g per 1 m².

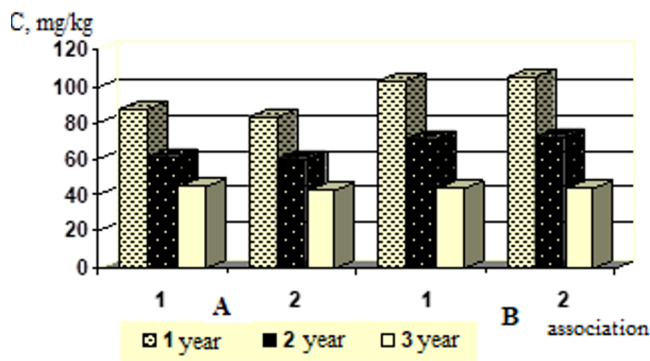


Fig. 2. Dynamics of the gross copper content (mg/kg) when applying a synthetic silicon-containing preparation (80 kg/ha) under perennial seeded meadows over a three-year observation period.

Note. The designations are similar to Figure 1.

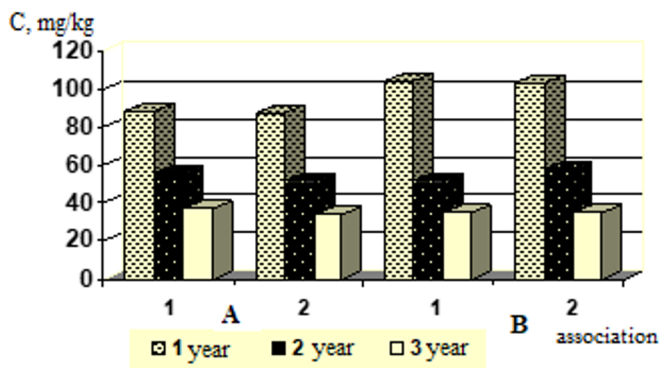


Fig. 3. Dynamics of the gross copper content (mg/kg) when applying a synthetic silicon-containing preparation (120 kg/ha) under perennial seeded meadows over a three-year observation period.

Note. The designations are similar to Figure 1.

The study of the dynamics of the gross copper content in the soil on sown perennial meadows using the DS meliorant showed a significant decrease in the toxicant concentration, which exceeded the APC by 2-3 times on model PP. According to the experimental data, the introduction of the preparation AD at a dose of 120 kg/ha reduces the concentration of copper to APC (34-37 mg/kg). Probably, long-term soil reclamation in seeded meadows with a silicon-containing preparation will give an even greater effect of reducing the gross concentration of copper in combination with the absorption capacity of meadow plants of the legume and cereal families. Therefore, soil grassing in combination with silicon-containing preparations is an effective method of land reclamation in areas of aerotechnogenic pollution.

Under experimental conditions, the effect of a silicon-containing preparation on the total zinc content in soils under sown perennial meadows was revealed. As in previous experiments, a significant decrease in the gross zinc concentration was recorded when AD was applied at concentrations of 50, 80, and 120 kg/ha.

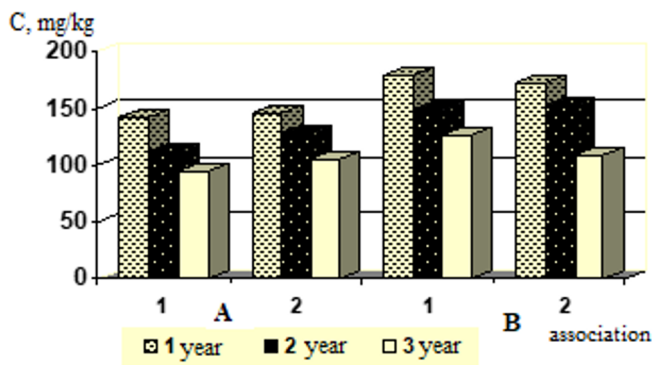


Fig. 4. Dynamics of the gross zinc content (mg/kg) when applying a synthetic silicon-containing preparation (50 kg/ha) under perennial seeded meadows over a three-year observation period

Note. Communities of seeded meadows: 1 dominant cow clover, 2 dominant common timothy. Zinc concentrations (mg/kg): A – in the variant 0.3 g per 1 m², B – in the variant 0.9 g per 1 m².

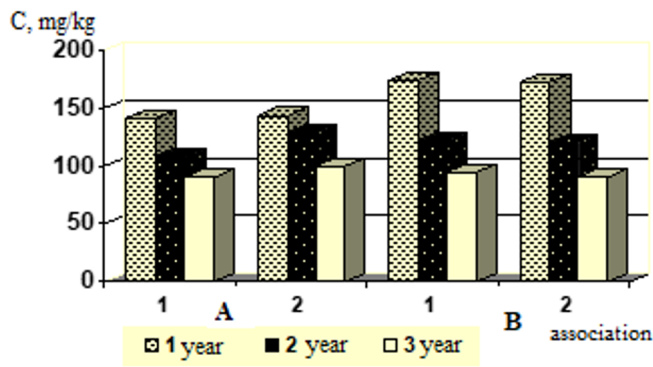


Fig. 5. Dynamics of the gross zinc content (mg/kg) when applying a synthetic silicon-containing preparation (80 kg/ha) under perennial seeded meadows over a three-year observation period

Note. The designations are similar to Figure 4.

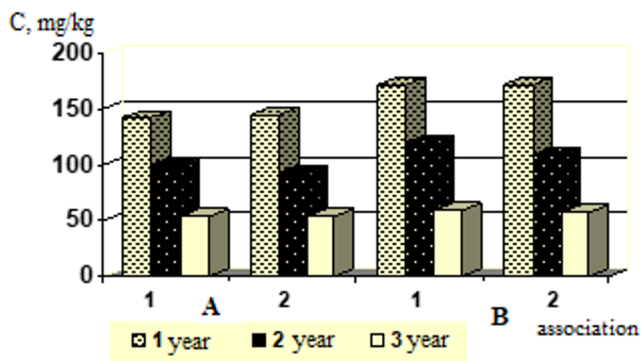


Fig. 6. Dynamics of the gross zinc content (mg/kg) when applying a synthetic silicon-containing preparation (120 kg/ha) under perennial seeded meadows over a three-year observation period

Note. The designations are similar to Figure 4.

A significant decrease in zinc content at different concentrations in the soil under experimental conditions is observed when AD is applied at doses of 80 kg/ha and 120 kg/ha. The maximum amount of AD of 120 kg/ha in the experiment reduces the concentration of zinc below the APC (54 mg/kg): in the seed community with cow clover. Long-term chemical reclamation using synthetic AD provides good indicators for reducing the gross concentration of zinc. It is also likely that this process is stimulated by the absorbing abilities of the grass (biomass).

Changes in the concentration of zinc and copper in the soil under annual seeded meadows of caper euphorbia and oat during reclamation with the drug AD also showed a downward trend.

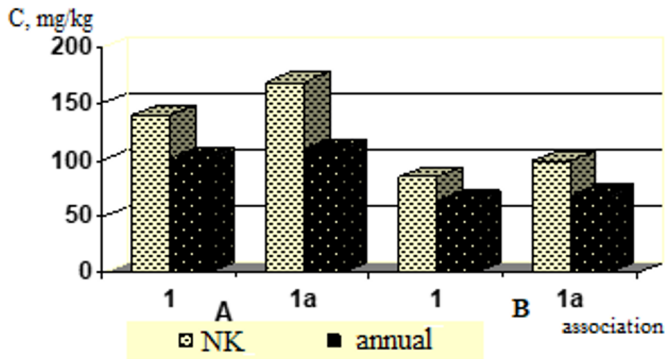


Fig. 7. Dynamics of the gross content of zinc (A, mg/kg) and copper (B, mg/kg) when applying a synthetic silicon-containing preparation (50 kg/ha) under sown meadows of caper euphorbia and oat

Note. Designations: nk – data for the beginning of the growing season, annual – after mowing the herbage to a green mass.

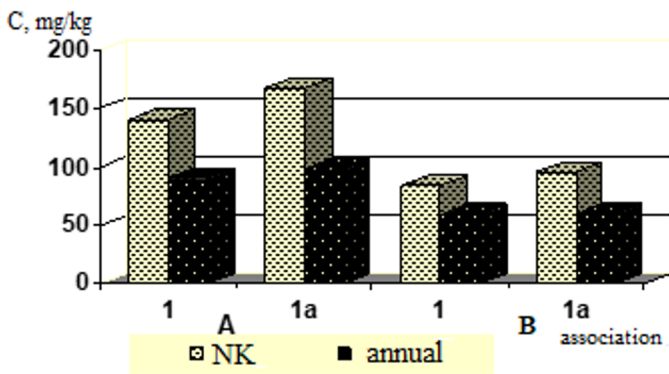


Fig. 8. Dynamics of the gross content of zinc (A, mg/kg) and copper (B, mg/kg) when applying a synthetic silicon-containing preparation (80 kg/ ha) under sown meadows of caper euphorbia and oat

Note. The designations are similar to Figure 7.

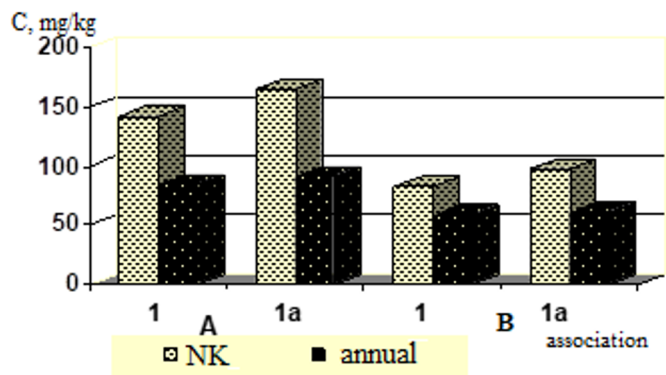


Fig. 9. Dynamics of the gross content of zinc (A, mg/kg) and copper (B, mg/kg) when applying a synthetic silicon-containing preparation (120 kg/ha) under sown meadows of caper euphorbia and oat

Note. The designations are similar to Figure 7.

All concentrations of the silicon-containing synthetic preparation caused a decrease in the gross content of two elements of the heavy metal group. The greatest effect is provided by the introduction of the preparation into the soil in doses of 80 kg/ha and 120 kg/ha. Nevertheless, the decrease in toxicants during the growing season of the annual grass mixture did not lead to indicators below the APC: the maximum decrease in the concentration of zinc and copper in soils was recorded when the preparation was added at a concentration of 120 kg/ha, the gross zinc content decreased to 1.4 APC, copper – to 1.7 APC.

In all variants of the experiment with seeded perennial and annual meadows, the metabolic acidity of soils also decreased with a decrease in zinc and copper concentration. The patterns found when applying AD to soils under perennial and annual seeded meadows were previously known: silicon-containing preparations reduce metabolic acidity [12, 13, 16]. The mobility of elements of the heavy metal group depends on this soil indicator: it decreases, and the absorption capacity of plant biomass increases.

Table 1. The effect of a synthetic silicon-containing preparation on the dependence of the gross content of copper and zinc on the values of the metabolic acidity of the soil in seeded meadows.

PH values at different doses of silicon-containing preparation	Correlation coefficient (R ²) / standard error	
	Cu	Zn
Perennial seeded meadow, cow clover		
50 kg/ha	– 0,81 / 0,20	– 0,83 / 0,14
80 kg/ha	– 0,89 / 0,12	– 0,87 / 0,18
120 kg/ha	– 0,95 / 0,24	– 0,92 / 0,31
Perennial seeded meadow, common timothy		
50 kg/ha	– 0,79 / 0,15	– 0,84 / 0,19
80 kg/ha	– 0,85 / 0,20	– 0,91 / 0,22
120 kg/ha	– 0,94 / 0,22	– 0,92 / 0,25
Annual seeded meadow: caper euphorbia and common oat		
50 kg/ha	– 0,77 / 0,22	– 0,85 / 0,22
80 kg/ha	– 0,81 / 0,20	– 0,85 / 0,20
120 kg/ha	– 0,90 / 0,18	– 0,91 / 0,15

In all the considered cases, increasing doses of a silicon-containing preparation showed the presence of an inverse correlation between individual parameters of the gross concentration of copper and zinc in the soil. The relationship between the two indicators – metabolic acidity and the gross content of elements of the heavy metal group – is

characterized as strong one. The most significant correlation coefficients are when AD is applied at doses of 80 kg/ha and 120 kg/ha. Thus, the prolonged action of the preparation helps to reduce the metabolic acidity of soils, the gross content of copper and zinc, which proves its detoxification ability.

The results of the determination of soil organic substances and their dynamics when applying AD in various concentrations are closely related to concomitant factors – external and internal biotic ones in natural meadows. Over the four-year observation period, the amount of OCC varied in a number of natural meadows; the OCC content is lower in the soil under natural communities, higher under sown ones: the content is statistically unreliable ($t_{pract} < t_{theoret}$).

In relation to the control, there was a pattern of increasing amounts of organic matter. In the variants of the experiment with seeded meadows, when plants of the papillonaceae family were included in the grass mixture, the OCC values increased.

Table 2. Content and reserves of organic carbon in the soils of seeded and natural meadows in the Non-Black Soil Zone of the Russian Federation.

Research option	OCC, % M±m	OCC reserves, t/ha, M±m	Weak <u>mg/100 g of soil,</u> % of soil OCC M±m
1 cow clover	2,23±0,04	51,12±2,8	780 / 41,5
2 common timothy	2,21±0,04	53,51±2,2	760 / 41,9
3 caper euphorbia + oat	2,31±0,05	57,85±2,5	788 / 47,3
4 community <i>Phalaridetum arundinaceae</i> Libbert 1931	2,17±0,02	49,92±2,4	755 / 39,0
5 <i>Heracleo sibirici–Alopecuretum pratensis</i> Bulokhov 2001	2,15±0,02	47,87±2,2	750 / 40,1
6 <i>Koelerio delavignei–Festucetum rubrae</i> Bulokhov 2001	2,10±0,04	45,34±1,5	750 / 40,0
7 control	1,90±0,03	43,15±2,2	

Since the largest root biomass was recorded in the experimental variants with legumes and cereals, the accumulation of organic carbon depends primarily on this internal factor.

When using ADC as a chemical meliorant, data on the OCC content were obtained (Table 3).

Table 3. The content and reserves of organic carbon in the soils of sown and natural meadows under conditions of chemical reclamation during three-year (for perennial sown meadows), four-year (for natural meadows), and one-year observations.

Research option	OCC, % M±m	OCC reserves, t/ha M±m	Weak <u>mg/100 g of soil,</u> % of soil OCC M±m
1 cow clover			
AD application dose is 50 kg/ha	2,33±0,04	58,11±2,9	790 / 47,9
AD application dose is 80 kg/ha	2,55±0,09	62,73±3,7	790 / 42,7
AD application dose is 120 kg/ha	2,63±0,08	61,90±3,9	800 / 48,2
2 common timothy			
AD application dose is 50 kg/ha	2,36±0,07	59,61±3,2	770 / 45,2
AD application dose is 80 kg/ha	2,58±0,09	61,51±3,7	790 / 45,8
AD application dose is 120 kg/ha	2,60±0,09	65,14±3,6	790 / 44,8
3 caper euphorbia + oat			
AD application dose is 50 kg/ha	2,36±0,06	61,26±3,1	810 / 50,2

AD application dose is 80 kg/ha	2,57±0,09	64,52±3,8	820 / 51,8
AD application dose is 120 kg/ha	2,59±0,09	67,72±3,7	825 / 51,5
4 community <i>Phalaridetum arundinaceae</i> Libbert 1931			
AD application dose is 50 kg/ha	2,40±0,07	54,67±2,9	785 / 43,4
AD application dose is 80 kg/ha	2,60±0,09	62,33±2,8	795 / 45,7
AD application dose is 120 kg/ha	2,64±0,09	64,11±3,4	805 / 45,9
5 community <i>Heracleo sibirici–Alopecuretum pratensis</i> Bulokhov 2001			
AD application dose is 50 kg/ha	2,36±0,05	54,57±2,9	780 / 44,1
AD application dose is 80 kg/ha	2,59±0,09	59,11±3,5	790 / 45,6
AD application dose is 120 kg/ha	2,60±0,09	62,59±3,6	805 / 47,9
6 community <i>Koelerio delavignei–Festucetum rubrae</i> Bulokhov 2001			
AD application dose is 50 kg/ha	2,44±0,06	53,92±2,7	790 / 43,1
AD application dose is 80 kg/ha	2,55±0,08	65,60±2,7	810 / 47,3
AD application dose is 120 kg/ha	2,57±0,09	65,76±2,9	815 / 45,7

4 Conclusion

It was found that during the four-year period of meliorant application, OCC values in soils grassed with natural and seeded vegetation increased for 3 and 4 years of observation. The differences in the OCC fixation differ unreliably with the variants without the addition of nanosilicon, nevertheless, OCC reserves increase significantly. The range of OCC accumulation as a result of long-term use of chemical meliorant is as follows: caper euphorbia + oats > common timothy > cow clover > koeleria-red fescue > two-source > cow parsnip-foxtail. The largest biomass of roots is recorded in the soil under the variants: common timothy, as well as under natural grasslands, since it is composed of racemose and rhizomatous perennial plants. There is a positive strong correlation between the indicators of organic carbon and root biomass ($R^2 = 0.74$), the most significant for communities with the common timothy ($R^2= 0.78$), under the koeleria-red fescue meadow ($R^2 = 0.75$). When applying AD, an increase in root mass is stimulated, as well as the activity of microorganisms, which, apparently, caused the above results. Nevertheless, in comparison with sown meadows, the greatest accumulation of OCC is determined for natural meadow communities, even with dry soils on the drylands ridges.

As for the dosage when applying the AD preparation to soils under natural and sown annual and perennial meadows, the introduction of silicon-containing preparation is recommended in doses of 80 kg/ha, in rare cases - 120 kg/ha.

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