Study of the Cyanobacteria effect on increasing in the rate of soil fertility in the arid zone

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ABSTRACT

We have studied the morphological and physicochemical characteristics of the soils of the Baer knolls in the Astrakhan region. Cyanobacterial communities were identified from the soil samples of the Baer knolls, the dominant forms of which was filamentous and heterocyst. The study of the cyanobacteria effect on increasing in the rate of fertility found that in all soil samples with cyanobacterial cultures was an increase the mass fraction of organic matter and pH of the water extract after three months of exposure.

Keywords: *Arid zone, Soil, Soil fertility, Cyanobacteria*

INTRODUCTION

The arid zone is an area of the desert-steppe type of soil formation, which is characterized by a low precipitation, high evaporation, dry air and the dominance of dry winds [1]. This zone includes the Astrakhan region, in which agriculture is due to artificial irrigation and use of fertilizers. A large area of the Astrakhan region is used as pastures for animals, in particular cattle. As a result, the problem of studying soil fertility is increasing. The search of most effective and biologically safe ways to increase agricultural productivity is highly relevant.

Microorganisms has taken the lead in decomposition of plant residues and in formation of complex organic substances, including humus [2]. For this reason, the importance of humic compounds in the formation of effective soil fertility should be only close relationship with activity of soil microorganisms, which are the basis of soil biodynamics [3, 4].

Cyanobacteria are an important component of soil biota. They fulfilled numerous and various tasks: synthesize a biologically active organic substances, participate in nitrogen fixation [5], soil aeration [6], modifing the physico-chemical properties of soils, stimulating the microbiological activity, and also in the processes of soil purification.

The positive effect of cyanobacteria has now been proven on the growth of higher plants [7, 8, 9]. The biodiversity of species composition and the higher number of certain species is an indicator of soil fertility. Soil cyanobacteria are capable of giving indication of the soil condition and participate in biological regulation of degraded soils [10].

The purpose of this paper is study of the soil condition and found to influence of cyanobacterial communities on the soil fertility in the arid zone.

1. MATERIALS AND METHODS

The object of the study was the soil cover of the Baer knolls near the Ivanchug village, Kamyzyaksky district of the Astrakhan region, especially its northern exposure. It is represented by different levels of grassland biocenoses, from high to low, which are hay fields and cattle pastures. Here the human pressures on the soil cover are minimal, therefore, the soils of this exposition were chosen as the object of research. The knoll landscape and sampling points are shown in Figure 1.

Also, the objects of research were eight cyano-bacterial communities, cultivated within five months on a liquid nutrient medium BG_N-11 in the scientific laboratory of biotechnology of the Astrakhan State University. Cyano-bacterial communities were isolated from the soils of the Baer knolls by method of cumulative cultures and cultivated in natural light [11].

Cyanobacteria identification was carried out according to the Komárek determinant (2013)

[12], Komárek , Anagnostidis (1998, 2005) [13, 14]. The cultures were ranked: T1 and T2 was isolated from brown arid medium loamy soil; T3 – from alluvial dark-humus slitized medium loamy soil; T4, T5 and T6 – from alluvial dark-humus hydrometamorphic medium loamy soil, T7 and T8 – from alluvial humus-gley medium loamy soil.

Figure 1 Satellite image of the research object.

A laboratory experiment was performed to identify the effect of cyanobacteria on soil fertility. It consists of eight containers with introduced cyanobacterial communities and eight control samples. For the experiment we used overgrown two-week cyanobacterial communities. The dry biomass of cyano-bacterial communities was ground in a mortar to a powdery state, put it to containers with concentration of community 0.1 g per 100 g of soil, and mixed. The biomass of cyanobacteria was determined by the gravimetric method by drying to constant weight at 37 ° C. The experimental and control samples were moistened of incubation with distilled water for three months.

We described changes of cyanobacteria effect on soil fertility and measured the indicators of organic matter and pH in control and experimental samples. Organic matter was determined by the Tyurin method modified by TsINAO (Central Agrochemical Service Research Institute) in accordance with GOST 26213-91 [15]. The pH of the water extract was determined according to GOST 26423-85 [16].

2. RESULTS AND DISCUSSION

Baer knolls is a zonal brown arid soil during the study. There are alluvial dark-humus slitized (desertifying) soils on the knoll in the study area. The knoll area is represented by alluvial dark-humus and humus-grade soils of various salinization and granulometric composition of soil.

Each type of soil is confined to certain relief elements and is formed with the participation of a kind of vegetation.

Due attention has been paid to the morphological description of soils, from which was derived the preliminary information about the processes. The soil fertility of the landscape is formed under the influence of these processes.

It was found that the main genetic features of brown arid soils are determined by the specificity of the conditions for their formation, in particular, the aridity of the climate and low productivity of vegetation in the laboratory and field studies. That is the reason for the brevity of the processes of formation and decomposition of humus substances. The humus mineralization and their rapid decomposition is happening in a dominance of aerobic processes. Therefore, a law capacity or lack of humus horizons and their low humus content are characteristic features of brown semi-desert soils. Also, these soils are characterized by high density and low porosity. The density values vary from 1.45 to 1.49 g / cm^3. The moisture and salt content are increasing uniformly with a depth. The amount of solid residue varies from 0.83% at the surface to 2.65% at a depth of 100 cm.

According to the morphological description, the studied brown soils are devoid of a humus horizon as a result of the influence of erosion processes. There is practically no vegetation. The granulometric composition varies from medium-loamy to heavy-loamy. The salt content was recorded from a depth of 20 cm, and gypsum-from 80 cm. There are signs of salinization in the accumulative-carbonate horizon.

The morphological description of the soil section No. 1, laid on the top of the Baer hillock, represented by brown arid saline slightly eroded medium loamy soil on the marine Lower Khvalyn sediments composing the Baer mounds, is given in Table 1.

Desertification of soils are a transitional step from a floodplain to a semi-desert. Drying and reducing the impact of floods contributes to a low moisture storage. The factors are formed and suppress the growth and development of grassland vegetation. These soils are characterized by significant compaction (1.36 - 1.53 g/cm^3). It hasn't much humus. If the process of desertification more pronounced then the soil has a high density. The salinity is different: from weak on the surface (0.49%) to strong, in the horizon B_{2s} (40-100 cm). The amount of solid residue is 3.39%. Salinity type is sulfate-chloride.

The granulometric composition varies from medium-loamy to heavy-loamy. Among the plants, salt-resistant species predominate (Salsola dendroides, eastern mortuk Eremopyrum orientale (L.) Jaub. & Spach, wheat mortuk Eremopyrum triticeum (Gaertn.) Nevski).

Table 1. Morphological description of soil section No. 1

Horizon	Depth, cm	Description of the horizon
BM	0 - 28	Light brown with a pale yellow tint, very dry, the first 2 cm loose, dense below, the structure is lumpy-powdery, single root inclusions, medium-loamy granulometric composition, vertical cracks (width 1-3 mm, height 5-15 cm), the border is smooth, transition in color, density, salt fading.
BCAs, sn	28 - 80	Brown, dry, compacted (looser than the previous one), the structure is lumpy-prismatic, multiple salt fades, there is a slight horizontal layering, heavy-loamy granulometric composition, the border is smooth, the transition in humidity and density.
BCs,cs	80 - 130	Brown, moist, loose, structureless, individual salt fades, gypsum crystals along cracks 2-3 mm wide, granulometric composition between medium and heavy loam.

The morphological description of the soil section No. 3, laid on the plume of the Baer hill,

represented by alluvial dark humus slitized (desertification) saline medium loamy soil on modern alluvial deposits, is given in Table 2.

Desertification of soils are a transitional step from a floodplain to a semi-desert. Drying and reducing the impact of floods contributes to a low moisture storage. The factors are formed and suppress the growth and development of grassland vegetation.

According to the morphological description, the studied soils have a small humus horizon, which, during the course of the processes of desertification and salinization, turned out to be very dense and hard, which directly affects the vegetation cover.These soils are characterized by significant compaction (1.36 - 1.53 g/cm^3). It hasn't much humus. If the process of desertification more pronounced then the soil has a high density.

The salt content was recorded from a depth of 5 cm across the entire soil profile. The salinity is different: from weak on the surface (0.49%) to strong, in the horizon B_{2s} (40-100 cm). The amount of solid residue is 3.39%. Salinity type is sulfate-chloride.

The granulometric composition varies from medium-loamy to heavy-loamy. Among the plants, salt-resistant species predominate (Salsola dendroides, eastern mortuk Eremopyrum orientale (L.) Jaub. & Spach, wheat mortuk Eremopyrum triticeum (Gaertn.) Nevski).

The morphological description of the soil section No. 3, laid on the plume of the Baer hill, represented by alluvial dark humus slitized (desertification) saline medium loamy soil on modern alluvial deposits, is given in Table 2.

Clearly pronounced stratification, alternation of layers of different granulometric composition and density are a distinctive feature of alluvial soils. The

Table 2. Morphological description of soil section No. 3

Horizon	Depth, cm	Description of the horizon
AUs	0 - 16	Dark gray, very dry, very dense, solid, fine - and medium-grained structure, granulometric composition of medium loam, inclusions of single roots, abundant salt fading, the border is smooth, the transition is clear in color.
BMs	16 - 40	Light brown, dense, but looser than the previous one, the structure is tile-prismatic (the tiles are not horizontal, but vertical), hard, the granulometric composition is heavy loam, there are few roots, less than in the previous one, salt spots with a diameter of 2-5 mm, the border is uneven, the transition is gradual in color.
BCAs, g	40 - 100	Dark brown, dryish, dense, hard, on the general background there are abundant salt spots with a diameter of 2-5 mm, rapid boiling from HCl of 10%, large bluish spots of glossing are noticeable in the lower part, the granulometric composition is medium loam.

value of density varies from 1.44 to 1.48 g/cm^3 layer-by-layer except for humus horizon, where the density is 1.21 g/cm^3.

The sign of gleying and ferruginization remain in the lower part of the profile. The degree of salinity ranges from low to high, and the humus horizon is characterized by strong salinity (1.54%). Salinity type is chloride-sulfate. Below the humus horizon, ochre-rusty spots are observed throughout the profile, indicating the redistribution of iron oxides under conditions of periodic waterlogging.

The morphological description of the soil section No. 5, laid on the near-carboniferous space, represented by alluvial dark humus medium-thick saline medium-loamy soil on modern alluvial deposits, is given in Table 3.

humus content is increased and promotes to the formation of a lumpy-powdery structure.

The morphological description of the soil section No. 6, laid on the near-carbon space, represented by alluvial humus-gley medium-loamy medium-loamy soil on modern alluvial and ilmen-alluvial deposits, is given in Table 4.

Thus, it was found that the soils of the studied landscape differ in physical and chemical properties and, accordingly, in potential fertility. Therefore, the cyanobacteria influence on the fertility of soils with such distinctive features. It is interesting actual study.

We were isolated eight cumulative cultures of cyanobacteria based on the soil samples. After five months of cultivation, green-brown membrane with a thickness of 1-2 mm were visually detected and located

Table 3. Morphological description of the soil section No. 5

Horizon	Deprh, cm	Description of the horizon
AUs	0 - 23	Black, fresh, compacted, the structure is fine - and medium-lumpy, the granulometric composition is medium loam, the abundant presence of plant roots and salt fading, the border is slightly wavy, the transition is clear in color.
B_1 s, g	23 - 40	Light brown, fresh, closer to loose, fine-lumpy-powdery structure, granulometric composition light loam, rare roots, rusty ferruginous-manganese nodules with a diameter of 1-2 mm, salt spots, the border is wavy, the transition is noticeable in color.
B_2 s, g	40 - 62	Fawn, fresh, closer to loose, granulometric composition of sandy loam, structureless, rare salt spots, red spots of iron and black manganese primers , the border is wavy, the transition is noticeable in density and color.
B_3 g	62 - 90	Brown, fresh, dense, granulometric composition is heavy loam, the structure is finely prismatic, fragments of shells, red spots of ash, the border is smooth, the transition is clear in color.
G	90 - 107	Bluish-gray-blue, moist, loose, structureless, red spots of ash, granulometric composition of clay.

Alluvial humus-gley soils submerged by annual seasonal floods. Due to seasonal waterlogging ascending and descending currents occurs alternately in these soils. The water-salt system of these soils is linked with these currents. During sampling, the groundwater was at a depth of 63 cm, and the salt content increased from 0.17 to 0.75% steadily with depth.

In addition, both anaerobic and aerobic processes take place in these soils. Anaerobic processes have a recurrent nature because they are replaced by aerobic ones after the recession of water. The gleying red spots of ferruginousness are on the general blue-gray background for that reason. These soils differ from the others in the darker color of the upper humus horizon, which has almost black color if it wet. In this horizon,

on the surface and in the water column. Microscopy of these membranes has shown the dominance of filamentous and heterocyst forms of the cyanobacteria *Phormidium* and *Nostoc* (Table 5).

Table 4. Morphological description of the soil section No. 6

Horizon	Depth, cm	Description of the horizon
AU	0 - 22	Black, fresh, loose, finely lumpy-powdery structure, granulometric composition medium loam, large reed roots, the border is slightly wavy, the transition is clear in color.
B_1 g	22 - 41	Light brown, moist, loose, the structure is finely lumpy, weakly expressed, the granulometric composition is sandy loam, on the general background there are red spots of ash, reed roots, the border is weakly expressed, the transition is gradual in color.
B_2 g	41 - …	Brown-gray with red spots of iron, wet, structureless, manganese nodules, granulometric composition of clay, from a depth of 63 cm groundwater.

Table 5. Edificators of cyano-bacterial communities

Cumulative cultures	Edificators of communities
T 1	*Nostoc, Leptolyngbya*
T 2	*Phormidium*
T 3	*Anabaena*
T 4	*Phormidium, Leptolyngbya*
T 5	*Phormidium, Nostoc*
T 6	*Nostoc*
T 7	*Phormidium, Desmonostoc, Leptolyngbya*
T 8	*Phormidium, Chroococcus*

Microscopy of the cumulative culture T1 found the dominance of *Nostoc* cyanobacteria in the presence of *Leptolyngbya*. In the cumulative culture T2 the edificator of communities was the *Phormidium*, in T3 – *Anabaena*, in T4 – *Phormidium,* in T5 *Phormidium* and *Nostoc* are dominated in the presence of *Leptolyngbya,* in T6 – *Nostoc*, in T7 – *Phormidium* and *Desmonostoc* in the presence of *Leptolyngbya*, in T8 – *Phormidium* in the presence of *Chroococcus.*

An active growth of cyanobacteria on the soil surface was visually observed after 1 month of exposure of soils with introduced cultures of cyanobacterial communities. The surface was covered with a dark green membrane. The soil in the containers was mixed and moistened with distilled water every two weeks. Filamentous and heterocyst cyanobacteria dominated in the microscopy of growth.

Determination of organic matter (humus) is the most important indicator of fertility. It showed that in all samples of soil with introduced cyanobacterial communities the mass fraction of organic matter increased (Table 6). This shows that the fertility of these samples increases.

Table 6. Influence of cyanobacteria on the mass fraction of organic matter in soil samples, %

Cumulative cultures	Control Sample	Soil samples with cyanobacteria
T 1	1,30	3,33
T 2	0,96	1,06
T 3	1,57	1,69
T 4	1,38	2,16
T 5	2,23	2,27
T 6	1,90	1,99
T 7	3,28	6,56
T 8	6,50	2,64

The content of organic matter was observed and increased 2.5 times in compared to the control in sample T1, 1.5 times – in sample T4 and 2.0 times – in sample T7.

Determination of soil acidity (pH) showed that in almost of soil samples with cyanobacterial communities the pH value increased (Table 7).

Table 7. Acidity (pH) of the water extract of soil samples

Cumulative cultures	Control Sample	Soil samples with cyanobacteria
T 1	7, 82	7, 59
T 2	8, 51	9, 05
T 3	8, 68	8, 85
T 4	8, 18	8, 02
T 5	8, 34	8, 59
T 6	8, 80	9, 03
T 7	8, 31	8, 08
T 8	8, 09	8, 29

As a result of low soil leaching by cyanobacteria the accessibility of many micro- and macroelements increases, such as phosphorus, calcium, potassium, sulfur, and molybdenum.

The studies, it was found that the soils of the landscape differ in physico-chemical properties and are represented by zonal brown arid soils, alluvial dark-humus slitized (desertifying), alluvial dark-humus and humus-gley soils of various granulometric composition and varying degrees of salinity.

Cyano-bacterial communities were isolated from eight soil samples of the Baer knolls. Microscopy showed the dominance of filamentous and heterocyst nitrogen-fixing forms of the cyanobacteria *Phormidium* and *Nostoc.*

In all soil samples with cyanobacterial cultures, an increase the mass fraction of organic matter was observed after three months of exposure. Cyanobacteria, assimilating carbon dioxide during their vital activity, made alkaline the soil, which is observed in all soil samples in compared to the control. The positive dynamics of changes of soil properties indicates an increase in fertility in accordance with the Decree of the Government of the Russian Federation No. 612.

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