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Targered Changes in the Natural and Semi-Artificial Arid Phytocenoses in the Contact Zone with the Agrocenoses: A System Control Model-Based Approach

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Abstract

The article presents the results of the study to analyze the plant and microbial soil associations in the composition of agrocenoses, natural steppe biocenoses and territorially integral areas of grasses on the border or within agrocenoses, mainly anthropogenic origin, named in the article as 'intrusions'. We show the key relationships between the main participants (47 plant species and 24 species of soil microorganisms, ranked by number in the association) in concurrence for the assimilation of soil trace elements. On the basis of data on the number, main phenological characteristics of plants and microorganisms, as well as the content of manganese, nickel, copper and zinc in the soil, the main consort bonds in this biosystem were identified. The analysis of the general influence of concrete intrusions on the adjacent agrocenosis made it possible to identify trace elements and types of soil microorganisms, which increase helped to limit the negative impact of intrusions. The obtained data can be used to form biotechnologies for optimization of agrocenoses in the conditions of the arid zone.

Keywords: arid plant communities, plant phenology, plant traits, plant-associated bacteria, soil microbial communities, iron, manganese, nickel, copper, phenotypic plasticity, environmental stress, plant biotechnology,

1. Introduction

From systems biology perspective, plant communities created by humans during agricultural or other work actively interact with microflora, other plants, representatives of the animal world, forming complex systems known as artificial biocenoses (Liu et al., 2014; Hudson et al., 2017). The dependence of the material and energy dynamics in biocenoses on the influence of soil and climatic conditions is considered in a number of quite extensive studies (El-Sayed et al., 2014; He et al., 2014; Mushaeva, 2015). A special place in the dynamics of such biocenoses is occupied by interactions with adjacent living systems, which, in the case of active influence on artificial biocenoses, acquire the character of intrusions with a dense junction or partial replacement of the artificial biocenosis territory. Biosystems in such areas can be attributed to semi-artificial biocenoses (Ndiribe et al., 2013; Ivantsova et al., 2017a).

According to modern concepts, microbial soil communities (soil microbiota) are considered to be the main control and producing component of terrestrial biocenoses. All soil bacteria are divided into four functional groups. Most of them are decomposers that consume simple carbon compounds, such as root exudates and plant residues. This type includes bacteria of the genus

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Actinobacteria, Proteobacteria and *Bacteroidetes* (Remans et al., 2012; Belogolova et al., 2013). The second group consists of symbionts, which form partnerships with plants. The most famous of them are nitrogen-fixing bacteria. The third group of bacteria are pathogens, including those of anthropogenic origin, capable of being causative agents of various diseases. The fourth group, called lithotrophs, such as sulfur bacteria, methanobacteria, iron bacteria, etc., receives energy from compounds of nitrogen, sulfur, iron or hydrogen instead of carbon compounds. Some of these species are important in nitrogen circulation and in the destruction of pollutants (Sarker et al., 2017). At the same time, the composition of bacterial communities may differ from plant to plant: some may be tied to different types of plants, others ones prefer only to certain (Ma et al., 2016).

Biotechnology can provide a meaningful change in the communities due to the introduction of biogenic components such as bacteria or fungi, and exposure to abiotic factors, for example acoustic and optical effects or chemical modifiers, using the basis of advanced achievements in biophysics, molecular biology, biological chemistry and bioengineering. General environmental laws are moving from the category of conditions for the functioning the agricultural production in one of the innovative scientifically based tools to ensure their effectiveness (Delmont et al., 2011; Veselý et al., 2012; Soussi et al., 2016; Tecon, Or, 2017).

However, at the moment the detailed studies on this subject, taking into account the natural and climatic specifics of agriculture in the arid zone, are not numerous. To develop a control system of agrobiocenosis with the application of biotechnological tools we need understanding the soil microbiota was designed to be a key point for the formation and therefore a key object of management the ecosystems (Pasternak et al., 2013; Ding et al., 2013).

The aim of the work was to substantiate and form the main ways of targeted impact on the soil microbiota to optimize the competitive relationship of semi-artificial biocenoses (intrusions) and artificial agrocenoses.

2. Materials and Methods

The study was carried out in 18 areas, which were a combination of natural steppe, artificial agrocenosis (barley field in the stage of technological maturity) and intrusion (Ipatov, 2015). Last ones represented the stable semi-artificial anthropogenically altered biocenoses with a predominantly negative impact on the contacting agrocenosis. According to the degree of intensity of negative impact on the basis of expert assessments of the results of environmental and botanical monitoring, the invasion was divided into three groups: high (1), moderate (2) and low (3) impact on the surrounding agrocenosis. Detailed characteristics of these communities were previously published (Ivantsova et al., 2017b).

Determination of trace elements in soil

Sample preparation included drying the samples to air-dry state, obtaining an average sample and preparation of an acid extract (Onistratenko et al., 2016). The analysis was performed by the precision method of atomic absorption spectrometry using the spectrometer "QUANTUM.Z" (production of KORTEK LLC, Russia). The results obtained during the measurement in μg/l were recalculated according to the established procedure and expressed in mg/kg of soil.

Isolation and analysis of soil microbial associations

To isolate the soil microorganisms the roots of the plants with surrounding rhizosphere soil were accurately separated. The samples of the root soil in the volume from 500 to 1000 mg were suspended in 100 ml of sterile 0.85 % sodium chloride solution and the working dilutions of the solution were prepared (1:100, 1:1000, 1:10 000). Incubation of seed produced at a temperature of 20-21 °C for 24-72 h. bacteria growth occurred on the agar with enzymatic beef hydrolysate. Then, we calculated the number of growing colonies and investigated morphological and cultural properties of the isolated microorganisms, identifying the dominant microorganisms (Pasternak et al., 2013; Ma et al., 2016).

Protein concentration in microbial biomass was determined by Bradford method at a wavelength of 595 nm against bovine serum albumin as an optical density control. The amount of lipids was determined by phosphoric-molybdenum reagent. Both indicators were expressed as percentage of biomass.

Quantitative data were processed using with the calculation of the indices adopted to characterize the parametric samples. Results were shown as M ± m. To prove the validity of differences between groups the Student criterion was applied with P values less than 0.05.

3. Results and discussion

General characteristics and ranking of flora

In the observed plant associations, 47 species were found and identified. Due to the rarity of detection and insignificant presence in plant associations, we excluded from the subsequent modeling the effects of 23 species: *Amaránthus retrofléxus, Centaurea diffusa, Centaurea ruthenica, Consolida regalis, Descurainia sophia L., Lycopsis arvensis, Lamium maculatum, Lepidium perfoliatum, Limonium gmelinii, Lolium perenne, Onobrychis arenaria, Poa praténsis, Polýgonum aviculáre, Raphanus raphanistrum, Rumex confertus Willd, Salvia aethiopis, Senecio jacobaea, Silene wolgensis, Stipa capillata, Tanacetum vulgaris, Thláspi arvénse, Turgenia latifolia* и *Vincetoxicum scandens*. Biodiversity of plant species, taking into account the conducted censorship for the construction of a prognostic model, is presented in the Table. 1.

Table 1. A frequency (F) and abundance (A) of identified participants in the studied plant communities*

Species	Agrocenosis		Intrusion		Steppe	
	F	A	F	A	F	A
Achillea micrantha or A. millefólium	-	-	-	-	4	2
Artemísia absínthium or A. lercheana	-	-	-	-	4	3
Atriplex tatarica	-	-	3	2	4	2
Brōmopsis inērmis	-	-	-	-	2	3
Ceratocephala orthoceras	-	-	1	2	1	1
Cichórium íntybus	2	2	2	2	3	3
Convōlvulus arvēnsis	3	2	2	1	-	-
Crepis tectorum	-	-	3	1	1	1
Delphínium dictyocárpum or D. consolida	2	1	1	1	2	1
Elytrigia repens	-	-	3	3	2	3
Euphórbia seguieriána or E. helioscopia	-	-	3	2	2	2
Filágo arvénsis	-	-	-	-	3	2
Hordeum vulgare	4	4	1	1	-	-
Lactuca tatarica	-	-	4	2	2	1
Medicago sativa	-	-	2	1	3	1
Melilótus officinális	2	1	1	2	3	2
Scorzonera mollis	-	-	-	-	4	3
Tragopógon dúbius	-	-	-	-	3	2
Tripleurospérmum inodórum	1	1	3	2	2	3
Xanthium albinum	-	-	3	2	-	-

* Only data on plants with the (F + A) > 4 are included

As can be seen from the presented data, the steppe phytocenoses were most often dominated by *Artemísia absínthium* and *Scorzonera mollis*, while *Atriplex tatarica* and *Lactuca tatarica* were typical dominants in the composition of intursions.

Results of determination of trace elements in soil

These data are presented in the Table 2.

Table 2. Content of mobile forms of soil microelements in studied biocenoses, mg/kg

Influence	Zone		
	Agrocenosis	Intrusion	Steppe
Manganese			
Low	154,1 ± 13,3	177,4 ± 19,2	90,5 ± 7,27 *
Moderate	373,1 ± 43,1 #	186,2 ± 13,3 *	250,2 ± 21,6 *#
High	315,9 ± 26,4 #	349,7 ± 33,7 #	305,6 ± 26,2 #
Nickel			
Low	8,1 ± 0,61	7,5 ± 0,65	2,3 ± 0,19 *
Moderate	14,1 ± 1,35 #	8,1 ± 0,32 *	4,4 ± 0,45 *#
High	14,2 ± 0,93 #	10,8 ± 1,55	9,9 ± 0,41 *#
Copper			
Low	11,6 ± 1,02	21,6 ± 1,76 *	11,8 ± 0,95
Moderate	31,2 ± 3,51 #	11,7 ± 0,22 *#	7,1 ± 0,53 *
High	35,3 ± 3,41 #	23,7 ± 1,95 *	25,2 ± 1,07 *#
Zinc			
Low	1,9 ± 0,16	3,9 ± 0,29 *	2,1 ± 0,18
Moderate	4,8 ± 0,29 #	2,2 ± 0,19 *	4,4 ± 0,50
High	9,2 ± 2,02 #	6,8 ± 0,43 #	5,8 ± 0,41 #

– differences between agrocenosis and two other zones
* – differences between low, moderate, and high influence to agrocenosis

Maximum concentration manganese was recorded at moderate influence of the intrusion in the territory of agrophytocenosis. The manganese concentration is 2.3 higher than the same value at low intrusion influence.

A strong nickel concentration was recorded at a moderate and high intrusion effect of 14.1 mg/kg and 14.2 mg/kg respectively, which is almost 2 times higher than at a low intrusion effect. The nickel concentration was at the same level of the intrusion values in the steppe.

The cuprum concentration in the intrusion is 2 times higher than the agrophytocenosis and plain. At moderate and high influence, the cuprum concentration is 3 and 1.5 times higher, compared with the irruption values, steppe and agrophytocenosis with low intrusion influence.

With the high intrusion influence on the agrophytocenosis, the zinc concentration was 9.2 mg/kg, which is almost 5 times higher than the low intrusion influence. The zinc concentration in the steppe, the intrusion had close values.

Results of the study of soil microbial communities

In the agrophytocenosis research was revealed the dominant plant *Hordeum vulgare*, in the intrusion *Atriplex tatarica, Lactuca tatarica* and the steppe *Artemísia absínthium*. The maximum value of microbial number was recorded in the intrusion territory and was 2.4, which is 1.5 times higher than in agrophytocenosis and 2.6 times in the steppe under conditions of low intrusion influence. With the increasing intrusion influence on the agrophytocenosis, there was an increase in microbial number in relation to the intrusion zone.

The following microorganisms species were found in the study areas of *Pseudomonas, Bac. Subtilis* (agrophytocenosis, Pseudomonas, Actinomyces albus (intrusion), Clostridium acetobutylicum, Actinomyces albus (steppe). Indicators of Microbial protein and Microbial lipids in agrophytocenosis remained at the same level, regardless of the degree of intrusion influence. Similar trends were observed in the intrusion and steppe. It should be noted that Microbial protein and Microbial lipids in agrophytocenosis were lower than in the territory of intrusion and steppe.

The significance of the obtained result requires clarification, which involves a seasonal research to form a representative sample within the framework of the analysis of relations in the "soil-microorganism" system.

Table 3. Properties of microbial communities in rhizosphere soil associated with dominant plants

Influence	Zone (plant dominants)		
	Agrocenosis (*Hordeum vulgare)*	Intrusion (*Atriplex tatarica, Lactuca tatarica)*	Steppe (*Artemísia absínthium)*
Microbial number, 10^6/g			
Low	1,6 ± 0,15	2,4 ± 0,18	0,9 ± 0,11
Moderate	1,4 ± 0,13	2,2 ± 0,17 #	0,8 ± 0,09
High	1,7 ± 0,12	3,0 ± 0,24 *#	0,8 ± 0,08 #
Microbial dominants			
Low Moderate High	*Pseudomonas, Bac. subtilis*	*Pseudomonas, Actinomyces albus*	*Clostridium acetobutylicum, Actinomyces albus*
Microbial protein, %			
Low	18,5 ± 1,33	24,9 ± 1,93 #	32,4 ± 2,76 #
Moderate	18,0 ± 1,30	32,5 ± 2,77 #	30,8 ± 2,56 #
High	16,2 ± 1,22	36,0 ± 3,04 *#	35,6 ± 2,98 #
Microbial lipids, %			
Low	3,4 ± 0,22	5,7 ± 0,37 #	6,1 ± 0,50 #
Moderate	3,6 ± 0,25	4,2 ± 0,31 *	5,8 ± 0,47 #
High	3,2 ± 0,19	4,0 ± 0,28 *#	5,5 ± 0,41 #

– differences between agrocenosis and two other zones
* – differences between low, moderate, and high influence to agrocenosis

Identification of relationships between soil microbiota and dominant plants

Two consort connections were established between the microbiota and plants: "the plant is the dominant representative of the microbial community" and "the soil is the dominant representative of the microbial community".

The relations nature between soil microorganisms groups, ranked by dominance to microbiocenosis, and plants, ranked in descending order of dominance in the community (Figure 1).

Primary linkage analysis for this phytocenosis showed that the strongest relationship is that between the group of aerobic bacteria (Pseudomonas) and such species as *Euphorbia helioscopia* and *Atriplex tatarica*. A similar situation applies to the anaerobic bacteria group (*Cl. Asetobutilicum*) and *Artemisia lercheana*.

The resulting arrow model allows not only to carry out the primary analysis of the connections, but also to compare microorganisms and plants with which they interact with each other, with subsequent reference to the agrophytocenosis.

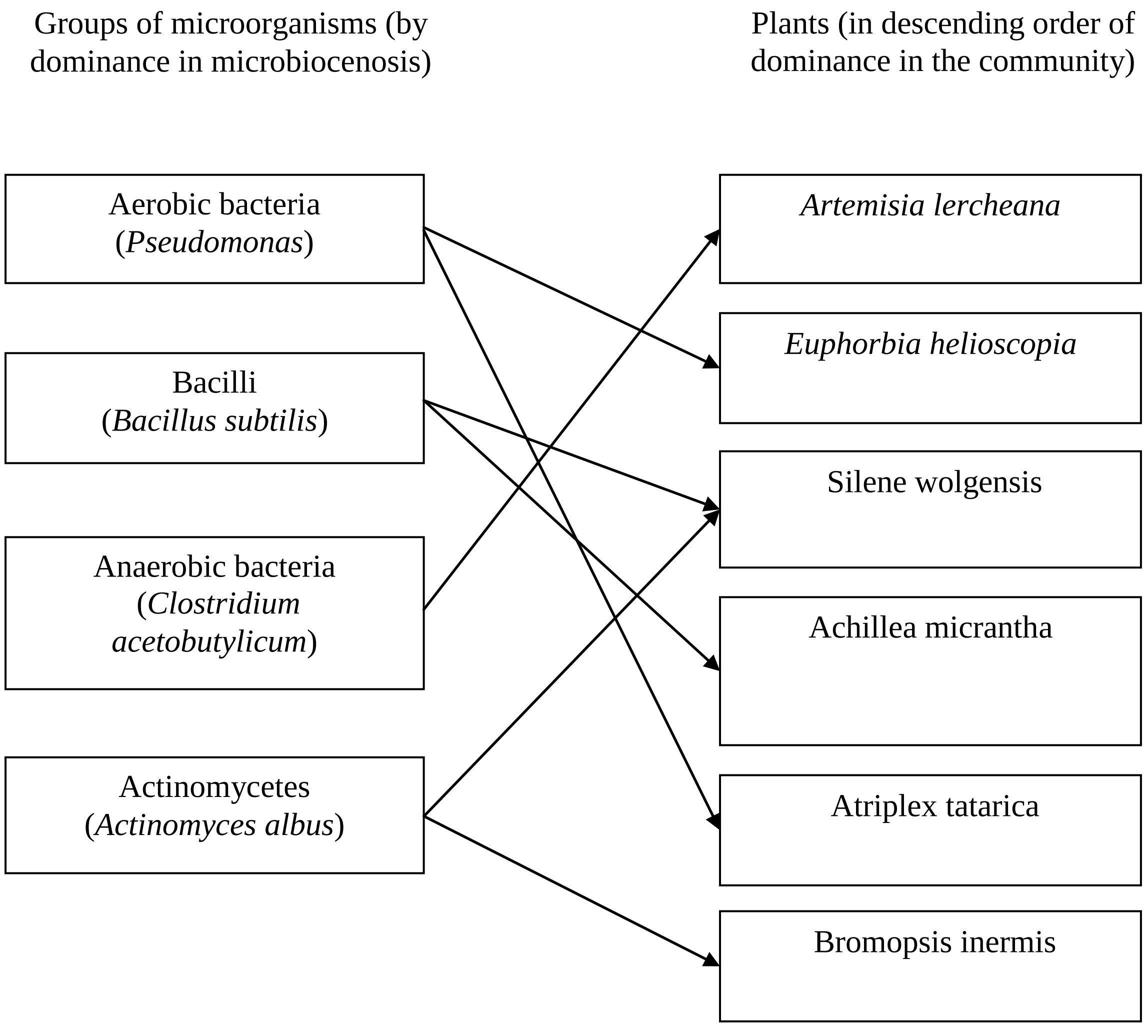

Fig. 1. The main consort relationships between different groups of soil microorganisms and plants (for example, plot № 3)

Discussion

The data obtained in studying the agrophytocenosis, the intrusion and the steppe is evidenced by the fact that with a high degree of intrusion there is a change in the trace elements composition, changes in the soil microflora. It is particularly noticeable that the presence of moderate or high intrusion influence leads to an increase in the trace elements concentration and their aggregates, which can have a negative influence on the agrophytocenosis (increasing soil toxicity to plants and microorganisms) (Totsche et al., 2018), and positively (by compensating for microelement deficiencies or stimulating growth) (Ma et al., 2016). It is important to note that such changes lead to the formation of "stress", which can both prevent the formation of agrophytocenosis, and protect agrophytocenosis from settling plants or microorganisms not peculiar to it (Drenovsky et al., 2012, Zefferman, 2015), it helps to reduce the probability of indirect competition between plants in the agrophytocenosis (Beck et al., 2010). All of the above is in good agreement with the experimental data, and in particular the increase in metal concentrations, has led to a decrease in the microbial number and species number in the agrophytocenosis.

This indicates that changes in the composition of the soil of trace elements, leads to a decrease in the microbial number communities, as well as prevents the growth of third-party plants and leads to the formation of new relationships between microorganisms groups (Drenovsky et al., 2012) and plants in agrophytocenosis.

4. Conclusion

The impact of intrusion on the agro-ecosystem is a complex, predominantly negative and is expressed in the following:

- on the periphery of the intrusion agrocenosis shows a decrease in projective cover and, as a consequence, a decrease in the biological productivity of the cultivated crop, which determines the yield as one of the economic indicators;

- the intrusion zone enhances the technogenic migration of elements, which determines the quality of agricultural products;

- technogenic intrusion is often associated with the formation of a special micro-relief of farmland, which affects the conditions of surface and underground runoff, changes the conditions of moisture and enhances the geochemical transfer of pollutants with their subsequent accumulation in the subsystem of agrocenosis " soil-plant»;

- the intrusion zone has a corrective effect on the trophic structure and the links between the main elements (soil, microbial communities, plants and fauna) in the surrounding agrocenosis.

Managing ecosystems as a whole is based on the assessment consortia connections between major structural elements: ecotope and biocoenosis.

As a result of the research two metals, such as manganese and copper, high concentrations of which contribute to the formation of biocenosis, to a minimum degree of competition to the adjacent agrocenosis, were identified. Similarly, three groups of microorganisms (Actinomycetes, Aerobic bacteria, Bacilli) were identified, whose dominance in microbial soil Association provides the same effect. These objects can be used to optimize the relationship between the agricultural lands and man-made intrusions in the conditions of arid zone.

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