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Bioecological characteristics of modern soil cover in subtropic regions of Azerbaijan

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ABSTRACT

The purpose of this study is to introduce innovation in the field of agriculture in Azerbaijan by determining the abundance of various ecotrophic groups of microorganisms (involved in the formation and mineralization of humic substances) in natural and cultivated gray-brown soils. Studying the microbiological indicators of humic substance transformation in virgin soils and determining the direction of these processes under the influence of anthropogenic factors in agrocenoses soils is considered relevant for the development of the agricultural sector in the Lankaran region. It was found that perennial woody vegetation increased the abundance of pedotrophic microorganisms by 17-21% and humate decomposers by 12-14% compared to completely natural soil. The correlation coefficient between the abundance of humate decomposers and the pedotrophic index was r=-0.685±0.09. Plowing natural gray-brown soils reduces the total humus content and the abundance of micromycetes, which form the peripheral portion of humic substances.

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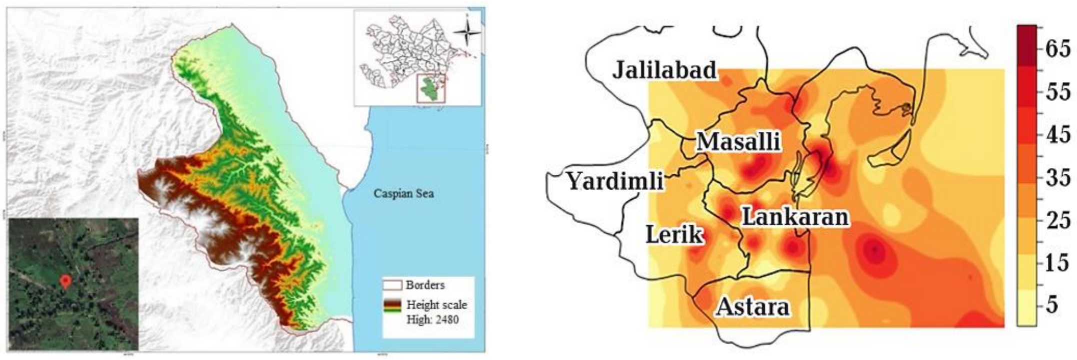
1. INTRODUCTION

Plowing up natural grey-brown soils significantly affects the microbiological complex of soils, and qualitative and quantitative changes in their structure and biodiversity occur. The presence of diverse groups of microorganisms in soil ecosystems, distinguished by their biological and biochemical specificity, determines the occurrence of soil processes and the formation of productive cenoses. The role of microorganisms in humus formation is multifaceted [1], [2]. They decompose organic matter, synthesize compounds that serve as structural components of humic substance molecules, and produce phenoloxidases, which oxidize polyphenols to quinones, followed by condensation into humus. Simultaneously with the synthesis of humic compounds in the soil, an opposite process occurs: their degradation, which is carried out by microorganisms and is important for the soil's organic matter reserves. If the rate of decomposition exceeds the rate of formation, the total amount of humus decreases, leading to dehumification [3]–[5]. When synthesis and degradation processes are in balance, available nutrients for plants are released, and the synthesis of new humic substances is compensated for. Humus decomposition, under such a balance, is a positive process. Given the general patterns and differences in the transformation of organic matter under the influence of anthropogenic soil-forming factors, it is important to study the abundance of ecotrophic microbial groups in virgin and reclaimed gray-brown soils of typical and ordinary natural soils and to determine the intensity of biological processes in them [6]–[8].

Establishing the biological activity of soils in the Shirvan plain, considered one of the main agricultural zones of Azerbaijan, where the subtropical climate has a positive effect on crop yields. The aim of this study was to determine the abundance of different ecological and trophic groups of microorganisms involved in the formation and mineralization of humic substances in natural and reclaimed gray-brown typical and ordinary natural lands; to study the microbiological indicators of humic substance transformation in virgin soils; and to determine the direction of these processes under the influence of anthropogenic factors in agrocenoses soils. Figure 1 shows the Lankaran zone regions agrocenoses [9]. Research area landscape digital elevation model map and soil bio-activity distribution map in Lankaran zone regions agrocenoses shown in (Figure 1(a)-(b)).



(a) (b)

Figure 1. Lankaran zone regions agrocenoses of (a) research area landscape digital elevation model map and (b) soil bio-activity distribution map

2. RESEARCH METHOD

For the study, soil samples were collected from a complete area of the natural steppe from a periodically mown area (every two years), and from plots of field crop rotation of an agricultural enterprise in the Lankaran district (38°47'13.7"N 48°50'03.3"E). During the period 2022-2024, an average of 40.6 kg of nitrogen fertilizers, 11.0 kg of phosphorus fertilizers, and 3.8 tons of manure per hectare of crop rotation area were applied to the soil of the field, as shown in Figure 2. Arable soil practice properties Pearson correlations are shown in Figure 3.

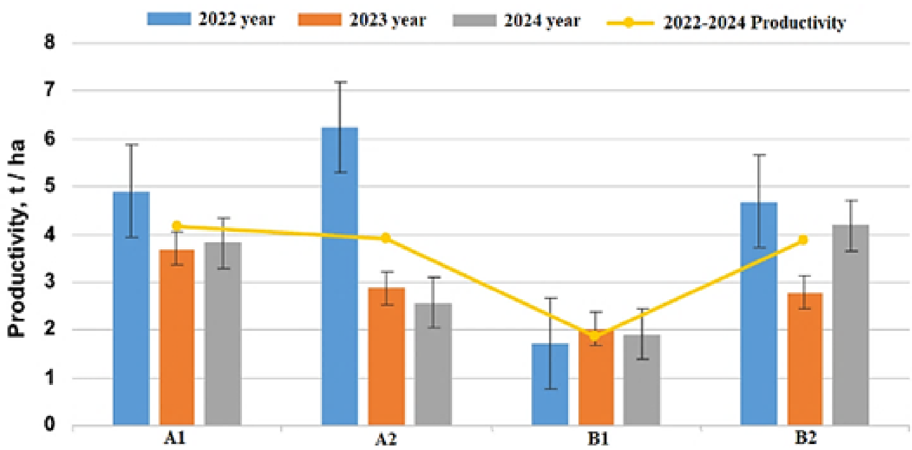


Figure 2. Productivity of crops depending on the use of fertilizers, t/ha (2022-2024 years)

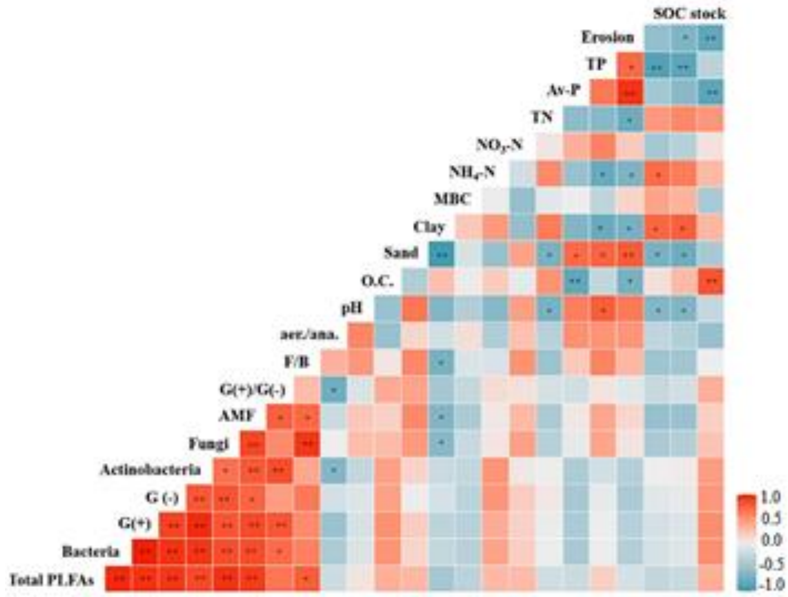


Figure 3. Pearson correlations between soil properties and agricultural practices in the Lankaran district (*$p<0.05$ and **$p<0.01$)

Soil biological studies were conducted in the 0-5, 5-20, and 20-40 cm soil layers [10]. Soil samples were collected in the third ten-day period of May during 2022-2024. Preparation and storage for laboratory aerobic biota analysis were conducted according to ISO 10381-6-2001. The abundance of various groups of soil microorganisms was determined using Zvyagintsev's methods by inoculating soil suspensions on solid nutrient media. The number of melanin-synthesizing microorganisms was determined using Czapek medium with a pH of 6.0, humate-degrading microorganisms were determined using a sodium humate medium, and pedotrophs were determined using soil agar. Total humus content in the studied soils was determined using Tyurin's method as modified by Simakov.

For the normal functioning of soil microorganisms, energy and nutrients are essential. For most soil microorganisms, these nutrients are organic matter [10]. The activity of soil microflora primarily depends on the supply or presence of organic plant residues in the soil [11], [12]. Microorganism populations were determined by plating soil suspension dilutions on solid nutrient media: i) ammonifying microorganisms on meat-peptone agar (MPA), ii) amylolytic microorganisms on starch-ammonia agar (SAA), iii) actinomycetes also plated on SAA, but counted separately, iv) pedotrophic microorganisms on soil agar, v) cellulose-degrading microorganisms on Hutchinson agar medium, and vi) microscopic fungi (micromycetes) on Czapek medium [13].

3. RESULTS AND DISCUSSION

According to many researchers, the mineralization of humic substances is determined by the biochemical activity of specific microflora. This group includes microorganisms capable of utilizing carbohydrates with the most stable cyclic and heterocyclic bonds. Some researchers argue against the specialization of microorganisms in humus decomposition and associate these processes with the activity of all soil microorganisms [14], [15]. The development of individual microbial groups can be used to determine the mineralization stage of plant residues in the soil. Streptomycetes participate in the mineralization of semi-decomposed plant residues-detritus. The number of colony-forming units of streptomycetes is shown in Table 1.

The highest streptomycete abundance is observed in the 0-5 and 5-20 cm layers of the natural soil variant and is due to the large amount of plant biomass, which includes cellulose and biopolymers, the mineralization of which forms detritus. Soil cultivation leads to a decrease in detritus content and streptomycete abundance [16], [17]. In the 0-5 cm layer of arable soil, the number of colony-forming units of streptomycetes is 8.4 times lower than in natural soil and 1.5 times lower in fallow land, while the difference was insignificant in the mown natural soil and shelterbelt variants.

The reduced input of plant residue biomass into the soil in the mown natural soil variant leads to a reduction in detritus and, consequently, an eightfold decrease in streptomycete abundance [18]. The 5-20 cm layer can be arranged in the following sequence: natural soil, mown natural soil, fallow land, forest belt, and arable land. The number of pedotrophs utilizing water-soluble fractions of organic matter and microorganisms that carry out deep destruction of the nuclear components of humus in a natural community is given in Table 2.

Research results show that plowing leads to a decrease in total humus content. Over 80 years of agricultural soil use, the total humus content in arable land decreases by 34% compared to natural soil, reaching 5.9% in the 0-20 cm layer. The difference in the numbers of pedotrophic and humate-degrading microorganisms between the 5-20 and 20-40 cm layers is within the experimental error. Not only do pedotrophic microorganisms influence the formation of mobile humic substances [2], [15], [19], [20]. The number of humate-degrading microorganisms changes insignificantly compared to the same soil layer in natural soil [21]. On average, in the 0-40 cm layer, the total humus content is 16% lower, the number of pedotrophic microorganisms is 62% lower, and the number of humate-degrading microorganisms is 32% higher compared to the natural soil. In the fallow soil, the total humus content increased by 19%, while the number of humate-decomposing microorganisms decreased by 35 and 166% (in different soil layers) compared to the arable land. Over 64 years of fallow soil, the soil humus content did not return to the levels of natural steppe gray-brown soils.

Perennial woody vegetation had a positive effect on humus formation and humification compared to the arable land [22]. This treatment yielded a 21% higher number of pedotrophic microorganisms and a 14% higher number of humate-decomposing microorganisms compared to the natural soil. The number of microorganisms decomposing the core portion of humic substances was 14% higher in the 0-40 cm layer compared to natural soil.

This suggests that the soil is receiving insufficient amounts of plant residues and energy material, which serve as a food source for microorganisms and, therefore, mineralization of soil humus occurs [23]. Based on the number of humate-degrading microorganisms in the 0-40 cm soil layer, all study variants could be arranged in the following descending order: shed belt-mown natural land, arable land, absolute natural land, and fallow. The number of pedotrophs and microorganisms that deeply degrade the nuclear aromatic components of humus in a natural biotope is shown in Table 3. The highest total humus content (7.33%) was found in the natural soil variant (in the 0-5 cm layer). This value decreased with depth, reaching only 5.39% in the 20-40 cm layer and 6.27% on average in the 0-40 cm layer. The number of pedotrophic microorganisms was higher in the upper layer (5-20 cm) than in the 20-40 cm layer. The difference in the abundance of humate-decomposing microorganisms across the soil layers was insignificant. The pedotrophic index, which characterizes the degree of soil organic matter utilization by microflora, was highest in the natural soil and mown soil variants in the 20-40 cm layer. Determination of the total humus content in ordinary gray-brown soils of the mountain steppe shows that, under the conditions of the steppe zone, in the upper layer (0-40 cm), mowing vegetation on virgin soil causes more significant changes than were observed in typical gray-brown soils of natural soil (see Table 3). The number of colony-forming embryos of pedotrophic microorganisms is 29% lower than in the virgin soil variant, due to the smaller amount of plant residues entering the soil. The number of humate-decomposing microorganisms in this variant, on the contrary, is 2.9 times higher than in the same layer of natural soil. With depth (20-40 cm), the humus content decreases to 4.59%, which is 17% lower. The number of pedotrophic microorganisms is 6.5% lower, and the number of humate-decomposing microorganisms is 28% higher compared to the natural soil variant. On average, in the 0-40 cm layer, the total humus content is 12% lower, the number of pedotrophic microorganisms is 21% lower, and the number of humate-decomposing microorganisms is 2.24 times higher than in the same layer of natural soil.

Compared to virgin soil, arable land is characterized by a significantly lower humus content [24]. The content of pedotrophic microorganisms, which decompose mobile humic substances, did not differ significantly from the natural soil variant in the 0-5 and 5-20 cm layers (3.1-14.2%) and was 34-43% higher than that of the mown natural soil variant. A similar trend in the number of pedotrophs was observed in the 0-40 cm layer: an insignificant difference between the natural soil variants and 23% higher than that of the mown natural soil. This suggests that the soil is receiving an insufficient amount of plant residues and energy material, which serve as a food source for microorganisms.

All study variants can be arranged in the following Table 4 order of decreasing number of humate-degrading microorganisms in the 0-40 cm layer: arable land, cut natural soil, and natural soil. The pedotrophic index (the ratio of the number of pedotrophic microorganisms to those decomposing organic forms of nitrogen) is lowest in arable land. This indicator did not differ between natural soil and mown soil. The correlation coefficient between the number of humate-degrading microorganisms and the pedotrophic index was $r = -0.685 \pm 0.09$. Cyclic melanin molecules, which are synthesized by micromycetes, can serve as the basis for the construction of peripheral components of humic compounds. The highest number of micromycetes was observed in the 0-5 cm layer under woody vegetation, with all variants then arranged in the following order: mown natural soil, absolute natural soil, arable land fallow. The same sequence was observed in the 0-40 cm layer. The number of micromycetes in all variants of typical gray-brown arable land was closely related to the number of pedotrophic microorganisms (r=0.59±0.06). This suggests that typical gray-brown absolute and mown natural soils provide favorable conditions for the formation of the peripheral part of humic substances. In the fallow land, an insignificant number of both humate-decomposing microorganisms and humate-synthesizing fungi was observed. Plowing natural gray-brown soils leads to a decrease in the number of micromycetes and a reduction in total humus content.

The different uses of typical gray-brown soils of the natural cenoses and ordinary gray-brown soils have led to a change in the direction of microbial transformation of organic matter [25]. Plowing virgin soils increases the number of humate-decomposing microorganisms by four times and 14% compared to completely natural soil [26]. Insufficient amounts of plant residues and energy material enter the arable soil, leading to humus mineralization.

Table 1. Number of colony-forming units of streptomycetes in typical natural fields with gray-brown soils under different phytocenoses, 10^6·CFU/g of soil

Experimental variant	Soil layer, cm		
	0-5	5-20	20-40
Absolutely natural soil	8.44±0.40	2.32±0.18	1.48±0.24
Mown natural soil	1.09±0.12	1.24±0.05	0.78±0.30
Forest belt	1.25±0.18	0.84±0.12	0.90±0.06
Arable land since 1936	0.98±0.11	0.62±0.07	0.25±0.08
Fallow since 1956	1.50±0.20	1.15±0.06	0.37±0.09

Table 2. Number of colony-forming units of pedotrophic and humate-degrading microorganisms, total humus under different gray-brown phytocenoses, typical natural cenoses, 10^6·CFU/g soil

Use case	Soil layer, cm	Total humus content, %	Pedotrophic microorganisms, 10^6·CFU/g	Humate-degrading microorganisms, 10^6·CFU/g
Absolutely natural soil	0-5	-	13.00±0.36	1.50±0.09
	5-20	8.81±0.04	14.10±0.18	1.25±0.06
	20-40	6.23±0.06	14.34±0.30	1.39±0.42
	0-40	7.52±0.05	13.8±0.28	1.38±0.19
Mown natural soil	0-5	-	13.73±0.06	2.72±0.42
	5-20	7.79±0.05	6.25±0.36	1.30±0.24
	20-40	5.32±0.06	5.58±0.30	1.44±0.12
	0-40	6.56±0.06	8.52±0.24	1.82±0.26
Forest belt	0-5	-	15.77±0.30	3.09±0.06
	5-20	8.60±0.04	13.08±0.48	1.62±0.09
	20-40	6.42±0.06	10.68±0.36	0.78±0.08
	0-40	7.50±0.05	13.2±0.38	1.83±0.08
Arable land since 1936	0-5	-	11.90±0.18	2.38±0.25
	5-20	5.9±0.04	11.50±018	1.78±0.18
	20-40	5.43±0.05	9.32±0.42	0.63±0.08
	0-40	5.6±0.05	10.9±0.26	1.60±0.17
Fallow	0-5	-	13.50±0.30	1.44±0.12
	5-20	7.33±0.03	11.50±0.28	0.67±0.18
	20-40	5.81±0.04	5.72±0.09	0.80±0.05
	0-40	6.57±0.04	10.2±0.22	0.97±0.12

Table 3. Number of colony-forming embryos of pedotrophic and humate-degrading microorganisms, total humus in ordinary gray-brown soils under various phytocenoses of natural cenoses

Use case	Soil layer, cm	Pedotrophic microorganisms, 10^6·CFU/g	Humate-degrading microorganisms,10^6·CFU/g	Pedotrophic index	Total humus content, %
Absolutely natural soil	0-5	9.60±0.15	0.72±0.12	2.46	7.33±0.11
	5-20	8.30±0.18	0.60±0.09	2.31	6.09±0.08
	20-40	7.12±0.23	0.53±0.09	4.45	5.39±0.09
	0-40	8.34±0.19	0.62±0.10	2.75	6.27±0.09
Mown natural soil	0-5	7.40±0.10	2.02±0.16	2.20	6.62±0.12
	5-20	6.61±0.18	1.48±0.11	2.39	5.53±0.11
	20-40	6.68±0.16	0,.68±0.11	4.28	4.59±0.10
	0-40	6.90±0.15	1.39±0.13	2.70	5.58±0.11
Arable land	0-5	9.90±0.15	2.60±0.25	2.01	5.29±0.08
	5-20	9.50±0.13	3.11±0.18	1.96	4.97±0.08
	20-40	7.11±0.15	2.11±0.17	1.32	3.98±0.09
	0-40	8.5±0.14	2.61±0.20	1.68	4.75±0.09

Table 4. The number of microorganism groups in the soils of the studied fields

Use case	Soil layer, cm	Amylolytics 10^6·CFU/g	Ammonifiers 10^6·CFU/g	Cellulose-degrading 10^4·CFU/g	Soil fungies 10^4·CFU/g
Absolutely natural soil	0-5	20.8±4.3	45.8±10.5	15.8±0.8	15.4±2.9
	5-20	16.4±4.7	36.8±3.1	11.2±4.2	8.2±0.2
	20-40	9.9±0.3	28.2±17.1	10.6±5.0	5.7±0.5
	0-40	9.5±1.4	12.2±2.5	5.4±0.6	19.6±3.2
Mown natural soil	0-5	19.5±0.9	26.6±3.6	17.5±7.2	26.3±10.6
	5-20	17.9±0.3	23.8±1.8	25.1±7.1	11.8±6.7
	20-40	9.9±0.3	24.3±5.9	3.1±2.7	13.9±7.2
	0-40	12.2±0.4	17.2±2.7	4.4±0.9	5.9±5.0

Note: mean±standard deviation

4. CONCLUSION

Perennial woody vegetation increased the number of pedotrophic microorganisms by 17-21% and humate-degrading microorganisms by 12-14% compared to an absolutely natural soil. The correlation coefficient between the number of humate-degrading microorganisms and the pedotrophic index was r=-0.685±0.09. Plowing natural gray-brown soils reduces the total humus content and the number of micromycetes that form the peripheral part of humic substances. Compared to natural soil, the arable land variant showed a significantly lower content of pedotrophic microorganisms that decompose mobile humic substances.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

This study received permission from the Azerbaijan Republic Government. All informed consents are based on the recommendations of the Ministry of Science and Education of the Azerbaijan on soil research.

ETHICAL APPROVAL

This study complies with the research ethics code, ensures that all procedures are carried out in accordance with established ethical standards, and has received approval from the relevant ethics committee.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [SSK], upon reasonable request.

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