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Assessment of the population dynamics of microorganisms in mountainous brown soils of Gobustan in relation to soil-climate conditions

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ABSTRACT

This study explores the seasonal variability of microorganisms in the mountain-brown soils of the Gobustan region of Azerbaijan and how this variability depends on soil-climatic conditions. As part of the research, soil samples were collected across all four seasons- spring, summer, autumn, and winter and microbial abundance was quantified using standard serial dilution and plate count techniques. The results showed that bacterial populations reached their peak during the early vegetation period (autumn), when soil temperature was moderate and moisture levels were optimal. In contrast, fungal colonies were more active in spring and summer, which is attributed to their differing responses to temperature conditions. Microorganisms are considered key indicators of soil biological activity, playing essential roles in nutrient cycling, nitrogen fixation, soil organic matter (SOM) formation, and element mobilization. Their diversity and abundance are directly linked to soil health and productivity. Microbiological diagnostics are crucial for evaluating the ecological status and fertility potential of soils, especially under semi-arid conditions. Seasonal monitoring of microbial indicators allows researchers to assess how environmental factors influence biological processes and the adaptive capacity of soil ecosystems. Most soil microbiota are concentrated in the upper 25–30 cm of the soil profile, where biological fractions occupy less than 1% of the total volume. Despite their small proportion, microorganisms respond rapidly to environmental changes and serve as sensitive indicators of soil conditions. Their ability to adapt and dominate under new conditions reflects shifts in soil health and ecological balance.

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INTRODUCTION

Microorganisms are considered indicators of soil biological activity, playing a key role in nutrient cycling, nitrogen fixation, soil organic matter (SOM) formation, and the mobilization of elements. The diversity and abundance of microorganisms in soil are directly linked to its biological activity (Chen *et al.*, 2024). Microbiological diagnostics in soils are among the primary tools for assessing productivity potential. Microbiological indicators reflect the characteristics of environmental factors and external influences. By measuring these indicators, it becomes possible to determine how seasonal changes affect microbiological processes in the soil.

Monitoring these changes also allows for the evaluation of the soil ecosystem's adaptive capacity. Diagnostics help assess the presence and activity of microorganisms, thereby estimating the soil's future productivity potential and self-recovery ability. Soil microbiota are mainly concentrated in the upper layer - approximately up to 25–30 cm deep (Mo *et al.*, 2024). In this layer, the biological fraction accounts for less than 1% of the soil volume and represents less than one-tenth of the total organic matter. Despite occupying a small portion of the soil volume, microorganisms provide an integrative assessment of soil health. They respond rapidly to environmental changes and adapt quickly to new conditions (Shi *et al.*, 2022). Microorganisms that are best adapted to the new environment tend to thrive and become dominant. This adaptability makes microbiological indicators highly sensitive parameters in evaluating soil health, and their variation can be considered a significant sign of changes occurring in the soil (Semenov *et al.*, 2025). Considering the above, the aim of the present study is to analyze the microbiological characteristics of mountain grey-brown soils located in the Gobustan region and to evaluate the impact of soil-climatic conditions on the dynamics of microbial abundance.

MATERIALS AND METHODS

The study was conducted at the Gobustan Experimental Station of The Research İnstitute of Crop Husbandary between 2024 october and 2025 july. Microbiological analyses were conducted at the Institute of Microbiology of the Azerbaijan National Academy of Sciences.

Microbiological analyses were carried out across four seasons to investigate the microbial dynamics in soils from wheat, barley, and control fields (non-cultivated). Sampling, inoculation into nutrient media, and determination of microbial abundance were performed based on standard microbiological methods (Bilay, 1982; Maheshwari, 2016; Mirchnik, 1988; Netrusov *et al.*, 2005). For the incubation of fungal colonies inhabiting the studied soils, the following agar-based nutrient media were used: malt extract agar (MEA), rice agar (RA), starch agar (SA), potato agar (PA), and agarified Czapek and Czapek-Dox media. For bacterial cultivation, meat-peptone agar (MPA) was employed. Soil samples were collected from four points per field, mixed thoroughly, and a composite sample was prepared. For fungal inoculation, a 10^3-fold dilution was applied; for bacterial inoculation, serial dilutions of 10^3, 10^4, and 10^5 were used. Fungal inoculation involved mixing 10 grams of soil with 90 ml of autoclaved distilled water, shaken intermittently every 15 minutes over a 2-hour period. For bacterial inoculation, 1 gram of soil was mixed with 100 ml of distilled water and shaken for 15 minutes. Fungal samples were inoculated under sterile conditions using both direct plating and 10^3-fold dilution. Bacterial samples were plated using direct inoculation and serial dilutions of 10^3, 10^4, and 10^5 onto appropriate Petri dishes. The incubation period for microorganisms was maintained at 28°C for 3 to 7 days.

RESULTS AND DISCUSSION

As a result of the microbiological analyses conducted within the scope of the study, the seasonal variation in the abundance of bacterial and fungal groups in soil samples was comparatively evaluated. The tables (Tables 1 and 2), figures (Figs 1 and 2), and accompanying explanations reflect the main trends of this variability. The number of microbial colonies

in soil samples was assessed from the beginning of cultivation (October) to its end (July). In autumn, the number of bacterial colonies in soil samples from the wheat field was recorded as 2.5×10^6, while in the barley field it was 2.6×10^6—4% higher than in the wheat field (Table 1, Fig. 1). In the control field (uncultivated), the number of bacterial colonies was 20.00% higher than in the wheat field and 15.38% higher than in the barley field. In winter, compared to autumn, the number of bacterial colonies decreased by 99.36% in the wheat field, 99.19% in the barley field, and 99.10% in the control field. However, in winter, the number of colonies in the barley field was 31.25% higher than in the wheat field. In the same season, the bacterial abundance in the control field was 68.75% higher than in the wheat field and 28.57% higher than in the barley field. Compared to winter, spring showed a significant increase in bacterial abundance across all three fields: 15 fold in the wheat field, 34.71 fold in the barley field, and 34.07 fold in the control field. In spring, the number of colonies in the barley field was 3.12 times higher than in the wheat field, reaching 7.5×10^5. In the control field, the colony count was 3.83 times higher than in the wheat field and 1.23 times higher than in the barley field, reaching 9.2×10^5. In summer, compared to spring, the number of bacterial colonies increased by 2.88 times in the wheat field, 2.40 times in the barley field, and 2.61 times in the control field. This increase indicates heightened microbial activity in the soil microbiota during the vegetation period. In this season, the number of bacterial colonies in the barley field was 2.61 times higher than in the wheat field, reaching 1.8×10^6. In the control field, the bacterial colony count was 3.48 times higher than in the wheat field and 1.33 times higher than in the barley field.

As illustrated in the Table 1, the highest levels of bacterial colony activity were observed in autumn and summer. The lowest microbiological activity occurred during the winter season. The seasonal progression of microbiological activity, in ascending order, can be summarized as follows: winter → spring → summer → autumn.

Table 1. Seasonal changes in the quantitative composition of bacterial populations

Season	Wheat	Barley	Control (Uncultivated)
Autumn	2.5×10^6	2.6×10^6	3.0×10^6
Winter	1.6×10^4	2.1×10^4	2.7×10^4
Spring	2.4×10^5	7.5×10^5	9.2×10^5
Summer	6.9×10^5	1.8×10^6	2.4×10^6

The quantitative composition of fungi in wheat, barley, and control field was investigated over four seasons. In autumn, the number of fungal colonies in soil samples collected from the wheat-planted field was 2.5×10^4, whereas in the barley-planted field it was 2.8×10^4, representing a 12.00% increase compared to the wheat field (Table 2). In the control field (uncultivated), the number of fungal colonies was 24.00% higher than in the wheat field and approximately 10.71% higher than in the barley field. In winter, relative to the autumn values for bacterial colonies, the decrease amounted to 89.02% in the wheat field, 91.07% in the barley field, and 99.65% in the control field.

Table 2. Seasonal changes in the quantitative composition of fungal populations

Season	Wheat	Barley	Control (Uncultivated)
Autumn	2.5×10^4	2.8×10^4	3.1×10^4
Winter	2.7×10^3	2.5×10^3	2.9×10^3
Spring	4.0×10^4	3.4×10^4	4.1×10^4
Summer	$2,8 \times 10^4$	2.9×10^4	3.2×10^4

During this season, the colony count in the wheat field was 8.00% higher than in the barley field. In the control field, the bacterial colony count was 7.41% higher than in the wheat field and 16.00% higher than in the barley field. In spring, compared to winter, the number of fungal colonies in the wheat, barley, and control fields increased by factors of 14.81, 13.60, and 14.14, respectively. In summer, compared to spring, a decrease in microbiological indicators was observed: 30.00% in the wheat field, 14.71% in the barley field, and 21.95% in the control field. However, in the barley field, the colony count increased by 3.57%, reaching 2.9×10^4. In the control (uncultivated) soils, the increase was higher than in both the wheat and barley fields, amounting to 14.29% and 10.34%, respectively.

As shown in Table 2, based on observations conducted in wheat, barley, and control fields, microbiological activity reached its minimum level in winter. In spring, maximum activity was recorded in all three fields. In autumn and summer, activity remained at a moderate level. Overall, the control field exhibited the highest colony counts. The seasonal order of microbiological activity, from lowest to highest, can be summarized as follows: winter – autumn – summer – spring**.**

During the sowing period, the monthly average temperature and precipitation levels were illustrated in Figs 1 and 2.

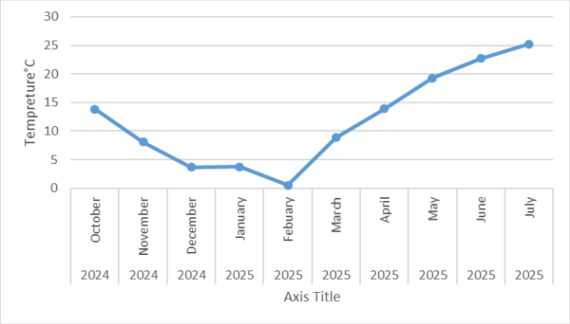

Fig. 1. Monthly temperature variation during the study period

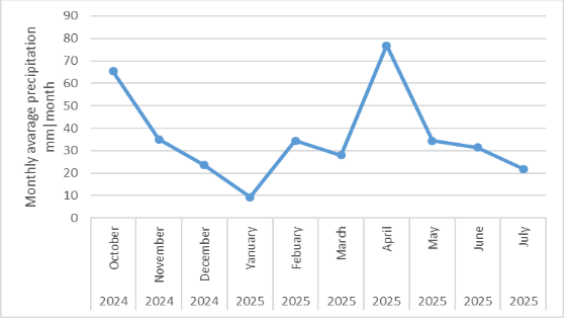

Fig. 2. Changes in average monthly precipitation during the study period

As illustrated, the decrease in monthly average temperature and precipitation during the winter season led to reduced activity of fungal and bacterial colonies in the soil. In contrast, the rise in temperature and precipitation during the spring months resulted in the highest seasonal activity of fungal colonies in the first year of the study (Fig. 3). Consequently, the activity of fungal colonies showed a seasonal increase in the following order: Winter-autumn-summer-spring. The seasonal trend in bacterial colony activity followed an increasing order: winter - spring - summer - autumn.

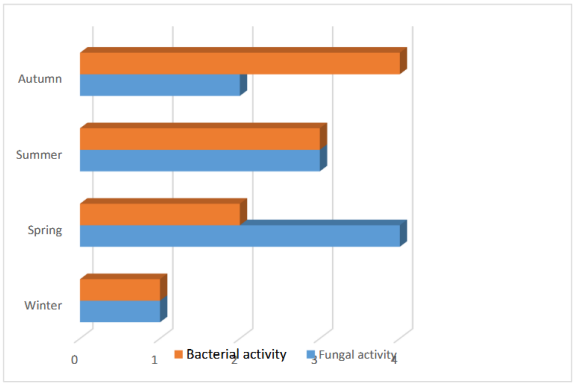

Fig. 3. Seasonal comparative changes in bacterial and fungal activity

Thus, the conducted research revealed that although the seasonal variation in the abundance of both bacteria and fungi was evident in barley and wheat cultivation fields, the peak bacterial counts were recorded in autumn, whereas fungal counts reached their maximum in spring. This difference is attributed to their distinct responses to temperature conditions.

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