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COMPARATIVE ANALYSIS OF ENZYMATIC ACTIVITY IN THE MOUNTAIN-FOREST BROWN AND YELLOW SOILS OF THE LANKARAN–ASTARA REGION AND ITS DIAGNOSTIC SIGNIFICANCE

Tural Ahadov[1]*

[1]*Institute of Geography, Ministry of Science and Education of the Republic of Azerbaijan*

**Corresponding author: ehedov-tural@mail.ru*

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Abstract. This study compares enzymatic activity in mountain-forest brown and yellow soils of the Lankaran–Astara region and examines its potential diagnostic value. Soil physicochemical properties, enzyme activities and culture-based microbiological indicators were assessed using field sampling and laboratory analyses. In the upper soil layer, the six measured enzyme activities were approximately 1.6–2.3 times higher in mountain-forest brown soils than in yellow soils. The reported humus contents were 6.51 ± 0.67% and 2.98 ± 0.54%, respectively, while soil pH values were 6.7 ± 0.3 and 5.2 ± 0.4. Enzymatic activity generally declined with depth and was higher in spring than in autumn. Reported correlations with humus content ranged from r = 0.72 to 0.88. The supplied polyphenol oxidase/peroxidase ratios differed between soil types, but an inconsistency in the yellow-soil ratio prevents a firm interpretation of humus type. Differences between the sampling scheme and table sample sizes, together with incomplete regression metadata, limit statistical verification. The reported patterns support further evaluation of enzyme activities as complementary indicators of soil biological condition, provided that the analytical and statistical inconsistencies are resolved.

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1. Introduction

Soil cover is a complex biological system that ensures the interaction between living organisms and the inorganic environment (Məmmədova, 2016). In recent decades, interest in studying the biological activity of soils has increased, since along with traditional physicochemical indicators, biological parameters are also of great importance in assessing soil fertility (Məmmədov & Xəlilov, 2002). Soil enzymes participate in processes such as the decomposition of organic residues, the synthesis of humus substances, the transformation of biogenic elements, and their conversion into forms available for plant uptake (Həsənova, 2018; Mustafayev, 2015).

The Lankaran–Astara region, located in the southeastern part of Azerbaijan, is distinguished by its unique natural and climatic conditions, complex relief structure, and diverse soil cover (Babayev et al., 2006). A humid subtropical climate prevails here: annual precipitation ranges from 1200 to 1600 mm and the average annual temperature is 14–15°C. The soil cover of the region follows the pattern of vertical zonality: yellow soils are widespread in the plains and lower mountain belt, while mountain-forest brown soils dominate in the middle mountain belt (İsgəndərov & Hüseynova, 2005; Qurbanov, 2010).

Previous regional studies addressed soil biological activity, humus status and selected enzyme indicators (Məmmədova, 2016; Qurbanov & Mustafayev, 2014; Xəlilov & Hüseynova, 2012). The present study brings together physicochemical, enzymatic and microbiological measurements for a comparative assessment of the two soil types.

The aim of this study is to comparatively investigate the activity of major enzymes in the mountain-forest brown and yellow soils of the Lankaran–Astara region, determine the patterns of their vertical distribution along the soil profile, identify the biochemical characteristics of humus formation based on the polyphenol oxidase/peroxidase (P/O) ratio, and evaluate the potential use of enzymatic activity indicators in soil diagnostics.

2. Materials and methods

2.1. Study area and sampling

The study focused on the widely distributed mountain-forest brown and yellow soils of the

Lankaran–Astara region. Soil samples were collected during the vegetation period (April–October 2023) from forest biogeocenoses unaffected by anthropogenic activity in the territories of Lankaran and Astara districts.

Sampling sites were defined as follows:

Mountain-forest brown soils: Around Tängärvu village, Lankaran district (38°46′ N, 48°44′ E), northeast slope, 10–15° gradient, 850–1050 m above sea level. Vegetation: broad-leaved forest dominated by hornbeam (*Carpinus betulus*), Oriental beech (*Fagus orientalis*), and chestnut oak (*Quercus castaneifolia*).

Yellow soils: Around Sancaradi village, Astara district (38°33′ N, 48°51′ E), southwest slope, 5–8° gradient, 150–350 m above sea level. Vegetation: *Paliurus spina-christi*, *Crataegus pentagyna*, *Cornus mas*, and sparse oak shrubs.

Five plots were selected for each soil type. Samples were collected at five points within each plot and composited separately for the 0–20, 20–40 and 40–60 cm depth intervals (Carter & Gregorich, 2008). The described design therefore comprises 30 composite samples (2 soil types × 5 plots × 3 depths). Samples were transported in polyethylene bags, air-dried, passed through a 2-mm sieve and stored dry until analysis. This pretreatment is relevant when interpreting potential enzyme activities.

2.2. Physicochemical analyses

Total organic carbon: dry combustion method using an elemental analyzer (Morgun & Kovda, 2020).

Total nitrogen was measured by the Dumas combustion method using a nitrogen analyzer (Carter & Gregorich, 2008).

Available phosphorus was extracted with 0.5 M $NaHCO_3$ at pH 8.5 using the Olsen extraction principle (Olsen et al., 1954); phosphorus in the extract was measured by ICP-OES.

Exchangeable potassium was extracted with 1 M NH_4OAc at pH 7.0 and measured by ICP-OES.

pH (water and salt): potentiometric method, soil:solution ratio 1:2.5, measured with Mettler Toledo pH meter.

Hydrolytic acidity was determined by extraction with 1 M CH_3COONa followed by NaOH titration, as described in the supplied analytical protocol.

Exchangeable Ca^{2+} and Mg^{2+} were measured by atomic absorption spectrometry after extraction with 1 M NH_4OAc at pH 7.0.

Particle size distribution: laser diffraction, measured with Mastersizer 3000 (Carter & Gregorich, 2008).

Moisture content: gravimetric method, drying at 105°C for 24 h.

2.3. Enzyme assays

Invertase: spectrophotometrically, based on sucrose hydrolysis over 24 h, expressed as mg glucose g^{-1} soil $(24\ h)^{-1}$ (Deng & Popova, 2011).

Catalase: gasometric method, measuring O_2 released in 1 min, expressed as mL O_2 g^{-1} soil min^{-1} (Karaca et al., 2011).

Urease: spectrophotometrically, based on urea hydrolysis over 24 h, expressed as mg NH_3 g^{-1} soil $(24\ h)^{-1}$ (Nannipieri et al., 2018).

Phosphatase: spectrophotometrically, based on hydrolysis of sodium phenylphosphate over 24 h, expressed as mg phenol g^{-1} soil $(24\ h)^{-1}$ (Gianfreda et al., 2005).

Polyphenol oxidase and peroxidase: spectrophotometrically, measuring quinone formed over 30 min, expressed as mg quinone g^{-1} soil $(30\ min)^{-1}$ (Wallenius & Vanhala, 2021).

2.4. Microbiological analyses

Culture-based microbial indicators were determined by plating on selective media. The following media and procedures were reported:

Mesophilic bacteria: on nutrient agar.

Actinomycetes: on Krassilnikov medium.

Fungi: on Czapek medium.

Cellulose-degrading microorganisms: on Hutchinson medium.

Azotobacter was assessed on Ashby medium and expressed as percentage coverage, rather than CFU per gram.

Other culture-based counts were expressed per gram of dry soil; units are given in Table 6.

2.5. Statistical analyses

Statistica 12.0 was used for data processing. Summary values were reported as mean ± standard deviation (SD). The supplied analysis used Student's t-tests for comparisons between soil types, Pearson correlations for relationships among variables, and linear regression for selected relationships. The table p-values and regression coefficients are reproduced as reported; their inferential interpretation is subject to the consistency limitations below.

2.6. Consistency and interpretation limits

The sampling scheme accounts for five independent plots per soil type and three depths, whereas several supplied tables specify n = 15 for a single depth and Tables 3 and 4 additionally list 60–80 and 80–100 cm. The provenance of the additional depths, seasonal replication and the distinction between field and analytical replicates are not documented. Accordingly, sample-size labels and p-values cannot be independently verified.

The yellow-soil P/O ratio and the combination of regression R^2, F and p also require the original observations and model output. All tabulated measurements are retained as supplied; interpretation is restricted where these inconsistencies matter.

3. Results and discussion

The reported physicochemical properties differ between the two soil types (Table 1). In the 0–20 cm layer, humus content was 6.51 ± 0.67% in mountain-forest brown soils and 2.98 ± 0.54% in yellow soils. Total nitrogen contents were 0.38 ± 0.05% and 0.21 ± 0.03%, respectively. The reported C/N ratios were 12.8 ± 1.2 and 11.2 ± 1.1. Bulk-density data, the depth basis for humus stocks and the conversion from measured organic carbon to humus were not supplied, so humus-stock estimates cannot be independently checked.

The reaction of the soil solution in mountain-forest brown soils is slightly acidic and close to neutral (pH 6.7 ± 0.3), whereas in yellow soils it is acidic (pH 5.2 ± 0.4), and the difference between them is statistically significant ($p < 0.01$). Hydrolytic acidity in yellow soils (5.62 ± 0.84 meq/100 g) is approximately three times higher than in mountain-forest brown soils (1.82 ± 0.46 meq/100 g). The sum of exchangeable bases is 29.8 ± 4.2 meq/100 g in mountain-forest brown soils and 15.2 ± 2.6 meq/100 g in yellow soils.

According to their texture, yellow soils are heavy clayey (physical clay 60.2 ± 4.8%), whereas mountain-forest brown soils are characterized by a medium clayey texture (physical clay 45.6 ± 4.2%). The content of physical clay significantly affects the water-physical properties of soils, particularly aeration and water permeability.

Table 1

Physical and chemical properties of the studied soils (0–20 cm; mean ± SD)

Property	Mountain-forest brown soils	Yellow soils	Reported p
Humus, %	6.51 ± 0.67	2.98 ± 0.54	<0.001
Total nitrogen, %	0.38 ± 0.05	0.21 ± 0.03	<0.001
C/N	12.8 ± 1.2	11.2 ± 1.1	<0.01
pH (water)	6.7 ± 0.3	5.2 ± 0.4	<0.01
pH (salt)	6.1 ± 0.3	4.5 ± 0.3	<0.01
Hydrolytic acidity, meq/100 g	1.82 ± 0.46	5.62 ± 0.84	<0.001
Sum of exchangeable bases, meq/100 g	29.8 ± 4.2	15.2 ± 2.6	<0.001
Base saturation, %	89.5 ± 4.2	67.8 ± 5.6	<0.01
Physical clay, %	45.6 ± 4.2	60.2 ± 4.8	<0.01

3.1. Enzymatic activity

The studies showed that the activity of all investigated enzymes in mountain-forest brown soils was reported to be higher than in yellow soils ($p < 0.05$). In the upper horizon of mountain-forest brown soils, invertase activity is 31.5 ± 2.4 mg glucose g^{-1} soil $(24\ h)^{-1}$, whereas in yellow soils it is 16.5 ± 1.4 mg glucose g^{-1} soil $(24\ h)^{-1}$ (Table 2). Catalase activity varies between 14.2 ± 1.2 mL O_2 g^{-1} soil min^{-1} in mountain-forest brown soils and 7.3 ± 0.6 mL O_2 g^{-1} soil min^{-1} in yellow soils. This indicator is consistent with a difference in potential oxidative activity in mountain-forest brown soils.

Urease activity is 0.50 ± 0.04 mg NH_3 g^{-1} soil $(24\ h)^{-1}$ in mountain-forest brown soils and 0.22 ± 0.02 mg NH_3 g^{-1} soil $(24\ h)^{-1}$ in yellow soils ($p < 0.001$). This difference is consistent with greater potential urea hydrolysis in mountain-forest brown soils. Phosphatase activity ranges from 0.45 ± 0.03 mg phenol g^{-1} soil $(24\ h)^{-1}$ in mountain-forest brown soils to 0.28 ± 0.02 mg phenol g^{-1} soil $(24\ h)^{-1}$ in yellow soils ($p < 0.01$). It is noteworthy that phosphatase activity in yellow soils is not as low as that of other enzymes. This can be explained by the stimulation of phosphatase synthesis by microorganisms in acidic soils where the availability of phosphorus for plants is limited.

Polyphenol oxidase activity was 0.53 ± 0.06 mg quinone g^{-1} soil $(30\ min)^{-1}$ in mountain-forest brown soils and 0.32 ± 0.04 in yellow soils. Peroxidase activities were 0.41 ± 0.05 and 0.26 ± 0.03 in the same units. The reported P/O ratios were 1.31 ± 0.11 and 0.89 ± 0.09. For yellow soils, the latter value differs from the quotient of the listed means (approximately 1.23). A mean of paired ratios need not equal a ratio of means, but paired observations are needed to verify the discrepancy.

Humus type should therefore not be assigned from the supplied P/O values alone.

Table 2

Enzymatic activity in the upper soil layer (0–20 cm; mean ± SD)

Enzyme	**Mountain-forest brown soils**	**Yellow soils**	**Reported p**
Invertase, mg glucose g^{-1} (24 h)$^{-1}$	31.5 ± 2.4	16.5 ± 1.4	<0.001
Catalase, mL O_2 g^{-1} min^{-1}	14.2 ± 1.2	7.3 ± 0.6	<0.01
Urease, mg NH_3 g^{-1} (24 h)$^{-1}$	0.50 ± 0.04	0.22 ± 0.02	<0.001
Phosphatase, mg phenol g^{-1} (24 h)$^{-1}$	0.45 ± 0.03	0.28 ± 0.02	<0.01
Polyphenol oxidase, mg quinone g^{-1} (30 min)$^{-1}$	0.53 ± 0.06	0.32 ± 0.04	<0.01
Peroxidase, mg quinone g^{-1} (30 min)$^{-1}$	0.41 ± 0.05	0.26 ± 0.03	<0.01
Reported P/O ratio*	1.31 ± 0.11	0.89 ± 0.09	<0.01

*The reported yellow-soil P/O ratio is 0.89 ± 0.09, whereas the quotient of the listed mean activities is 0.32/0.26 ≈ 1.23. These are distinct statistics, but the reported ratio cannot be verified without paired measurements. Sample sizes and reported p-values require the clarification described in Section 2.6.

Enzymatic activity in both soil types shows a decreasing trend with increasing depth (Tables 3 and 4). In mountain-forest brown soils, at a depth of 40–60 cm, invertase activity is 10.3 ± 0.9 mg glucose g^{-1} soil (24 h)$^{-1}$, catalase activity 5.3 ± 0.5 mL O_2 g^{-1} soil min^{-1}, urease activity 0.15 ± 0.01 mg NH_3 g^{-1} soil (24 h)$^{-1}$, and phosphatase activity 0.24 ± 0.02 mg phenol g^{-1} soil (24 h)$^{-1}$. In yellow soils, at the same depth (40–60 cm), these indicators are 5.7 ± 0.5, 2.8 ± 0.2, 0.06 ± 0.01, and 0.14 ± 0.01, respectively. This decrease is mainly associated with the reduction of organic matter content with depth, as well as the decline in the number and activity of microorganisms.

Table 3

Enzymatic activity along the mountain-forest brown soil profile (mean ± SD)

Depth, cm	**Invertase, mg glucose g^{-1} (24 h)$^{-1}$**	**Catalase, mL O_2 g^{-1} min^{-1}**	**Urease, mg NH_3 g^{-1} (24 h)$^{-1}$**	**Phosphatase, mg phenol g^{-1} (24 h)$^{-1}$**
0–20	31.5 ± 2.4	14.2 ± 1.2	0.50 ± 0.04	0.45 ± 0.03
20–40	18.6 ± 1.5	9.8 ± 0.8	0.28 ± 0.02	0.32 ± 0.02
40–60	10.3 ± 0.9	5.3 ± 0.5	0.15 ± 0.01	0.24 ± 0.02
60–80	5.8 ± 0.5	2.8 ± 0.3	0.08 ± 0.01	0.16 ± 0.01
80–100	2.4 ± 0.2	1.2 ± 0.1	0.03 ± 0.005	0.09 ± 0.01

Table 4

Enzymatic activity along the yellow soil profile (mean ± SD)

Depth, cm	**Invertase, mg glucose g^{-1} (24 h)$^{-1}$**	**Catalase, mL O_2 g^{-1} min^{-1}**	**Urease, mg NH_3 g^{-1} (24 h)$^{-1}$**	**Phosphatase, mg phenol g^{-1} (24 h)$^{-1}$**
0–20	16.5 ± 1.4	7.3 ± 0.6	0.22 ± 0.02	0.28 ± 0.02
20–40	9.2 ± 0.8	4.5 ± 0.4	0.12 ± 0.01	0.20 ± 0.02
40–60	5.7 ± 0.5	2.8 ± 0.2	0.06 ± 0.01	0.14 ± 0.01
60–80	2.8 ± 0.2	1.4 ± 0.1	0.03 ± 0.005	0.09 ± 0.01
80–100	1.2 ± 0.1	0.6 ± 0.05	0.01 ± 0.002	0.05 ± 0.005

3.2. Seasonal variation

Seasonal variations have a significant effect on enzymatic activity (Table 5). In both soil types, enzymatic activity is higher in spring compared to autumn. In mountain-forest brown soils, invertase activity in spring is 32.8 ± 2.5 mg glucose g^{-1} soil (24 h)$^{-1}$, while in autumn it is 28.4 ± 2.2 mg glucose g^{-1} soil (24 h)$^{-1}$ ($p < 0.01$). This difference is associated with the increased activity of microorganisms at the beginning of the vegetation period.

Table 5

Seasonal changes in enzymatic activity (0–20 cm; mean ± SD)

Enzyme	Mountain-forest brown soils		Yellow soils	
	Spring	Autumn	Spring	Autumn
Invertase, mg glucose g^{-1} $(24\ h)^{-1}$	32.8 ± 2.5	28.4 ± 2.2	17.2 ± 1.4	14.8 ± 1.2
Catalase, mL O_2 g^{-1} min^{-1}	14.8 ± 1.2	13.2 ± 1.1	7.8 ± 0.6	6.5 ± 0.5
Urease, mg NH_3 g^{-1} $(24\ h)^{-1}$	0.52 ± 0.04	0.44 ± 0.03	0.24 ± 0.02	0.19 ± 0.02
Phosphatase, mg phenol g^{-1} $(24\ h)^{-1}$	0.48 ± 0.03	0.42 ± 0.03	0.30 ± 0.02	0.25 ± 0.02

3.3. Microbiological indicators

In mountain-forest brown soils, the total number of microorganisms is 5.48 ± 0.62 million CFU/g, while in yellow soils it is 2.98 ± 0.46 million CFU/g (Table 6). The number of bacteria in mountain-forest brown soils is 4.22 ± 0.48 million CFU/g, compared to 2.18 ± 0.36 million CFU/g in yellow soils; actinomycetes are 0.98 ± 0.16 million CFU/g and 0.44 ± 0.12 million CFU/g, respectively; and microscopic fungi are 0.52 ± 0.08 million CFU/g and 0.42 ± 0.08 million CFU/g. In yellow soils, the relative proportion of microscopic fungi (14.1% of total microorganisms) is higher than in mountain-forest brown soils (9.5%), which is associated with the greater resilience of fungi compared to bacteria in acidic soils.

Azotobacter develops at a high level in the upper horizon of mountain-forest brown soils (68.4 ± 8.6% coverage), whereas in yellow soils it is observed only in isolated points (14.6 ± 4.2% coverage). This difference is related to the acidic reaction of yellow soils ($p < 0.001$).

Table 6

Microbiological indicators in the upper soil layer (0–20 cm; mean ± SD)

Microorganisms	Mountain-forest brown soils	Yellow soils	Reported p
Mesophilic bacteria, million CFU/g	4.22 ± 0.48	2.18 ± 0.36	<0.01
Actinomycetes, million CFU/g	0.98 ± 0.16	0.44 ± 0.12	<0.01
Microscopic fungi, million CFU/g	0.52 ± 0.08	0.42 ± 0.08	>0.01
Cellulose-decomposing microorganisms, thousand CFU/g	98.4 ± 14.2	48.6 ± 9.8	<0.01
Azotobacter, % coverage	68.4 ± 8.6	14.6 ± 4.2	<0.001
Total microorganisms, million CFU/g	5.48 ± 0.62	2.98 ± 0.46	<0.01

3.4. Correlations and regression

The supplied correlation matrix indicates positive associations of enzyme activities with humus content (r = 0.72–0.88) and total nitrogen (r = 0.68–0.85; Table 7). Correlations with pH ranged from 0.42 to 0.62, while those with moisture ranged from 0.38 to 0.68. Phosphatase activity was negatively correlated with available phosphorus (r = −0.52). These associations describe the reported dataset and do not establish causal effects.

Table 7

Reported correlations between enzyme activities and soil properties (r; reported n = 30)

Property	Invertase	Catalase	Urease	Phosphatase
Humus	0.86	0.78	0.88	0.72
Total nitrogen	0.82	0.70	0.85	0.68
pH	0.58	0.62	0.52	0.42
Moisture	0.48	0.68	0.52	0.38
Physical clay	-0.52	-0.58	-0.48	-0.35
Available phosphorus	0.42	0.35	0.38	-0.52

Correlations are reproduced as reported. The allocation of the 30 observations among plots and depths, and the treatment of repeated observations, are not specified.

The reported linear relationship between invertase activity (y) and humus content (x) was $y = 4.62x + 1.84$, with $R^2 = 0.74$. The relationship between urease activity (y) and total nitrogen (x)

was $y = 0.84x + 0.12$, with $R^2 = 0.72$. The supplied F statistics and significance levels cannot be reconciled with the stated observation count without the original model output; the equations and R^2 values are retained descriptively.

The upper-layer enzyme activities in Table 2 are consistently higher in mountain-forest brown soils. Comparison with other regions requires matched substrates, incubation conditions, sample pretreatment and reporting units; numerical agreement alone does not demonstrate equivalent soil biological activity (Nannipieri et al., 2018).

The high enzymatic activity in mountain-forest brown soils can be explained by the following factors:

Organic matter quantity and quality. Mountain-forest brown soils are formed under more diverse forest vegetation, resulting in a higher quantity and better quality of organic residues. As shown in Table 7, there is a very strong correlation between enzymatic activity and humus content ($r = 0.72–0.88$). This is consistent with the interpretation that organic matter serves as the primary substrate for microbial development and enzyme synthesis.

Soil reaction (pH). The near-neutral reaction of mountain-forest brown soils (pH 6.7 ± 0.3) is favorable for the optimal activity of most enzymes. Studies indicate that enzymes such as invertase, urease, and catalase exhibit maximum activity under near-neutral conditions. In contrast, the acidic reaction of yellow soils (pH 5.2 ± 0.4) limits enzymatic activity. Nevertheless, the relatively high activity of phosphatase in acidic soils (0.28 ± 0.02 mg phenol g^{-1} (24 h)$^{-1}$) can be considered an adaptive mechanism. In acidic soils, the availability of phosphorus for plants is limited, prompting microorganisms to synthesize additional phosphatase to release phosphorus from organic compounds.

Moisture regime. The moisture content in mountain-forest brown soils is relatively optimal (25–35%). In yellow soils, particularly during the autumn–winter period, excessive moisture (40–50%) promotes anaerobic processes. The low catalase activity in yellow soils (7.3 ± 0.6 mL O_2 g^{-1} min^{-1}) may be associated with the suppression of oxidative processes under anaerobic conditions.

Soil texture may influence aeration and substrate availability. The supplied matrix shows negative correlations of physical clay with all four enzyme activities ($r = −0.58$ to $−0.35$). These relationships are consistent with a possible physical constraint but do not, by themselves, demonstrate the mechanism.

The diagnostic interpretation of the P/O ratio requires caution. Oxidative enzyme assays provide information on potential transformations of phenolic compounds, but they do not directly quantify humic and fulvic acid fractions. The unresolved yellow-soil ratio and missing paired observations prevent validation of a humus-type classification from these data.

Role of microorganisms. In mountain-forest brown soils, the high abundance of microorganisms, particularly bacteria and actinomycetes (5.48 ± 0.62 mln CFU/g), stimulates enzyme synthesis. In yellow soils, although the total microbial count is lower (2.98 ± 0.46 mln CFU/g), the relatively high proportion of microscopic fungi (14.1%) is characteristic of acidic soils. Fungi are resistant to acidic conditions and therefore play a primary role in the decomposition of organic matter in such soils.

The results indicate potential value in combining enzyme activities with physicochemical indicators. Their wider diagnostic use requires consistent sampling, standardized assays and comparison against independently measured soil functions (Karaca et al., 2011; Nannipieri et al., 2018).

4. Conclusions

The mountain-forest brown and yellow soils of the Lankaran–Astara region differ significantly in their physicochemical properties and biological activity. Mountain-forest brown soils are characterized by high humus content (6.51 ± 0.67%) and total nitrogen (0.38 ± 0.05%) and a near-neutral reaction (pH 6.7 ± 0.3). In contrast, yellow soils have low humus (2.98 ± 0.54%) and total nitrogen (0.21 ± 0.03%), acidic reaction (pH 5.2 ± 0.4), and a heavy texture (physical clay 60.2 ± 4.8%).

The six enzyme activity means in the upper layer were approximately 1.6–2.3 times higher in mountain-forest brown soils than in yellow soils. Invertase, catalase, urease and phosphatase activities were 31.5 ± 2.4, 14.2 ± 1.2, 0.50 ± 0.04 and 0.45 ± 0.03 in their respective assay units, compared with 16.5 ± 1.4, 7.3 ± 0.6, 0.22 ± 0.02 and 0.28 ± 0.02 in yellow soils. The significance levels remain subject to clarification of independent replication.

The reported P/O values require verification before use as diagnostic criteria. In particular, the yellow-soil value of 0.89 ± 0.09 is not directly reconciled with the supplied mean enzyme activities. Independent humus-fraction measurements are needed to support a humus-type interpretation.

The reported dataset shows positive associations between enzyme activities and humus content ($r = 0.72–0.88$) and total nitrogen ($r = 0.68–$

0.85). These patterns and the supplied regression equations are descriptive until observation counts, model output and the handling of repeated measurements are clarified.

Enzymatic indicators may complement physicochemical measurements in assessments of soil biological condition and fertility. Their diagnostic reliability in the study area requires resolution of the sampling, ratio and statistical inconsistencies and independent validation against soil functions.

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LƏNKƏRAN–ASTARA BÖLGƏSİNİN DAĞ-MEŞƏ QONUR VƏ SARI TORPAQLARINDA FERMENTATİV FƏALLIĞIN MÜQAYİSƏLİ TƏHLİLİ VƏ ONUN DİAQNOSTİK ƏHƏMİYYƏTİ

Tural Əhədov[1]*
[1]*Azərbaycan Respublikası Elm və Təhsil Nazirliyinin Coğrafiya İnstitutu, Azərbaycan*
**Məsul müəllif: Ehedov-tural@mail.ru*

Xülasə. Məqalədə Lənkəran–Astara bölgəsinin dağ-meşə qonur və sarı torpaqlarında fermentativ fəallıq müqayisə edilir və onun torpaq diaqnostikasında istifadəsi qiymətləndirilir. Torpaqların fiziki-kimyəvi xassələri, fermentlərin fəallığı və mikrobioloji göstəricilər çöl və laboratoriya məlumatları əsasında təhlil olunur. Üst qatda tədqiq edilmiş altı fermentin orta fəallığı dağ-meşə qonur torpaqlarda sarı torpaqlara nisbətən təxminən 1,6–2,3 dəfə yüksəkdir. Humusun miqdarı müvafiq olaraq 6,51 ± 0,67% və 2,98 ± 0,54%, pH isə 6,7 ± 0,3 və 5,2 ± 0,4 təşkil etmişdir. Fermentativ fəallıq dərinliyə doğru azalma meyli göstərmiş, yazda payıza nisbətən yüksək olmuşdur. Humusun miqdarı ilə fermentativ fəallıq arasında verilmiş korrelyasiya əmsalları 0,72–0,88 intervalındadır. Sarı torpaqlar üçün polifenoloksidaza/peroksidaza nisbətindəki uyğunsuzluq humus tipinin etibarlı təyinini məhdudlaşdırır. Nümunə sayı və dərinliklər üzrə metodika ilə cədvəllər arasındakı fərqlər, həmçinin natamam reqressiya məlumatları statistik nəticələrin yoxlanmasını tələb edir. Fermentativ göstəricilərin torpağın bioloji vəziyyətinin əlavə meyarları kimi tətbiqi bu uyğunsuzluqlar aradan qaldırıldıqdan sonra qiymətləndirilməlidir.

Açar sözlər: *Lənkəran–Astara bölgəsi, dağ-meşə qonur torpaqlar, sarı torpaqlar, fermentativ fəallıq, invertaza, katalaza, P/O nisbəti, torpaq diaqnostikası*

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