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SOIL ENZYMATIC ACTIVITY AS A BIOINDICATOR OF MICROELEMENT DYNAMICS IN IRRIGATED SIEROZEM SOILS UNDER SEMI-ARID CONDITIONS

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Abstract. This study focuses on the role of soil enzymatic activity as a sensitive bioindicator of microelement dynamics in irrigated sierozem soils under semi-arid environmental conditions. Particular emphasis is placed on the interaction between soil microorganisms, enzyme systems, and trace elements such as Fe, Zn, and Cu.Soil enzymes, including dehydrogenase, urease, catalase, and phosphatase, play a critical role in nutrient cycling and organic matter transformation. Their activity reflects the intensity of biochemical processes occurring in the soil ecosystem. In this research, soil samples were collected from different depths (0–20, 20–50, 50–100, and 100–200 cm) and analyzed using standard biochemical and physicochemical methods.The results demonstrate a strong correlation between enzyme activity, humus content, and microelement availability.

Keywords: Soil enzymes, dehydrogenase activity, urease, phosphatase, soil microbiology, microelements, soil fertility, irrigated soils, sierozem, biochemical processes

Аннотация. В данном исследовании основное внимание уделяется роли ферментативной активности почвы как чувствительного биоиндикатора динамики микроэлементов в орошаемых сероземных почвах в условиях полузасушливой среды. Особое внимание уделяется взаимодействию почвенных микроорганизмов, ферментных систем и микроэлементов, таких как Fe, Zn и Cu. Ферменты почвы, включая дегидрогеназу, уреазу, каталазу и фосфатазу, играют важную роль в круговороте питательных веществ и превращении органических веществ. Их активность отражает интенсивность биохимических процессов, происходящих в экосистеме почвы. В данном исследовании образцы почвы были взяты с различных глубин (0–20, 20–50, 50–100 и 100–200 см) и проанализированы стандартными биохимическими и

физико-химическими методами. Результаты показывают сильную корреляцию между активностью ферментов, содержанием гумуса и доступностью микроэлементов.

Ключевые слова: Ферменты почвы, дегидрогеназная активность, уреаза, фосфатаза, микробиология почвы, микроэлементы, плодородие почвы, орошаемые почвы.

Annotatsiya. Ushbu tadqiqot yarim qurg‘oqchil sharoitlarda sug‘oriladigan bo‘z tuproqlarda mikroelementlar dinamikasining sezgir bioindikatori sifatida tuproq fermentativ faolligini baholashga bag‘ishlangan. Tadqiqotda tuproq mikroorganizmlari faoliyati, ferment tizimlari hamda temir (Fe), rux (Zn) va mis (Cu) kabi mikroelementlar o‘rtasidagi o‘zaro bog‘liqlik tahlil qilindi.Tuproq namunalari 0–20, 20–50, 50–100 va 100–200 sm chuqurliklardan olinib, fizik-kimyoviy hamda biokimyoviy usullar asosida tahlil qilindi. Dehidrogenaza, ureaza, fosfataza va katalaza fermentlari faolligi tuproqdagi mikrobiologik jarayonlar intensivligini ko‘rsatuvchi indikator sifatida baholandi.Natijalar tuproqning yuqori qatlamida fermentativ faollik eng yuqori ekanligini, chuqurlashgan sari esa keskin kamayishini ko‘rsatdi. Mikroelementlar miqdori ham xuddi shunday vertikal kamayish qonuniyatiga ega ekanligi aniqlandi. Fermentlar faolligi va mikroelementlar o‘rtasida kuchli ijobiy korrelyatsiya mavjudligi qayd etildi.

Kalit so‘zlar: tuproq fermentlari, dehidrogenaza, ureaza, fosfataza, mikroorganizmlar, mikroelementlar, tuproq unumdorligi, sug‘oriladigan tuproqlar, bo‘z tuproqlar, biokimyoviy jarayonlar

INTRODUCTION

Soil enzymes are considered reliable indicators of soil health because they respond rapidly to changes in environmental conditions. Unlike chemical properties, enzymatic activity reflects the functional state of the soil ecosystem.The aim of this study is to evaluate the relationship between soil enzymatic activity and microelement distribution, and to determine their role in maintaining soil fertility under irrigated conditions. Soils represent one of the most complex and dynamic components of terrestrial ecosystems, playing a fundamental role in global biogeochemical cycles and agricultural productivity. According to global estimates, soils store approximately 2,400–2,500 Pg of organic carbon, which is nearly three times higher than the amount of carbon present in the atmosphere. At the same time, soil degradation processes affect more than 33% of the world’s soils, particularly in arid and semi-arid regions where climate stress and intensive land use significantly reduce soil fertility. In semi-arid agroecosystems, irrigated soils such as sierozems are especially vulnerable to degradation due to low organic matter content (typically 0.5–1.5%), high evaporation rates, and increasing anthropogenic pressure. These soils are characterized by alkaline pH conditions (pH 7.5–8.5), which significantly influence the mobility and availability of essential microelements. Studies show that under such conditions, up to 40–60% of zinc (Zn) and 30–50% of iron (Fe) may

become unavailable for plant uptake due to precipitation and adsorption processes. Soil microelements, including iron (Fe), zinc (Zn), and copper (Cu), play a crucial role in plant nutrition and microbial metabolism.

MATERIALS AND METHODS

Study Area and Soil Characteristics. The study was conducted in irrigated sierozem soils typical for semi-arid regions. These soils are characterized by low organic matter content, alkaline pH, and moderate biological activity. The study was conducted in irrigated agricultural lands located in a semi-arid region of the Tashkent province. The climate of the study area is sharply continental, characterized by hot and dry summers and relatively cold winters. The average annual temperature ranges between 13–15°C, while annual precipitation is approximately 300–450 mm, most of which occurs during winter and early spring. Evaporation significantly exceeds precipitation, creating conditions of moisture deficit that necessitate regular irrigation. The soils of the study area are classified as typical sierozem soils, formed under arid conditions with limited organic matter accumulation. These soils are characterized by a low humus content (0.8–1.2%), alkaline reaction (pH 7.5–8.3), and medium to heavy loamy texture. Carbonate accumulation is commonly observed in subsurface horizons. The soils exhibit moderate biological activity, which is strongly influenced by irrigation practices, organic matter input, and seasonal climatic variations.

One possible approach to solving soil monitoring tasks is the use of soil biological activity indicators. The biological activity of the soil plays an important role in the process of its fertility formation and establishment. The use of biological indicators allows for a more accurate assessment of soil conditions and their degree of degradation, as well as foreseeing disturbances and predicting changes occurring within them. Biochemical research on soils in Uzbekistan has been conducted by A.A. Abdurakhmonov [1], U.U. Usmonov, [2], N.B.Raupova and ZS.Gulamova others [3,4,5,6,7].

Soil Sampling and Preparation. Soil samples were collected from four depth layers:

-0–20 cm
-20–50 cm
-50–100 cm
-100–200 cm

Samples were air-dried, sieved (2 mm), and stored for laboratory analysis.

Microbiological Analysis. Microbial biomass and activity were indirectly evaluated through enzyme activity. The abundance of microorganisms decreases with soil depth due to limited organic substrates.

Statistical Analysi. Correlation analysis was used to determine relationships between enzyme activity, humus content, and microelements. Statistical analysis was performed to evaluate the relationships between soil enzymatic activity,

microelement distribution, and depth-related variability. Descriptive statistics, including mean values, standard deviation, and coefficient of variation (CV), were calculated to assess the variability of the studied parameters across soil layers.Pearson correlation analysis was applied to determine the strength and direction of relationships between enzymatic activity (dehydrogenase, urease, phosphatase, catalase) and microelements (Fe, Zn, Cu). Correlation coefficients (r) were interpreted according to standard statistical thresholds, where values of $r > 0.7$ indicate strong relationships.In addition, a Soil Biological Activity Index (SBAI) was developed as an integrative indicator combining normalized enzyme activities to evaluate the overall biological status of the soil profile. The index was calculated as the average of standardized enzyme activity values across all measured enzymes, allowing comparison between different soil depths.

Enzymatic Activity Distribution

Table 1.

Vertical distribution of soil enzymatic activity

Depth (cm)	Dehydrogenase (mg TPF/kg)	Urease (mg NH_4^+/kg)	Phosphatase (mg P/kg)	Catalase (ml O_2/g)
0-20	4.8	52.4	38.2	3.5
20-50	3.1	39.6	27.4	2.6
50-100	1.9	24.8	18.6	1.9
100-200	1.1	15.2	10.3	1.2

Enzyme activity sharply decreases with depth.

Microelement Content

Table 2.

Microelement istribution

Depth (cm)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
0-20	32.4	1.42	0.72
20-50	24.6	1.10	0.55
50-100	18.2	0.86	0.41
100-200	12.7	0.63	0.29

Relationship Between Enzymes and Microelements

A strong positive correlation was observed between:

-Dehydrogenase activity and Fe content

-Urease activity and Zn availability

-Phosphatase activity and organic matter

This indicates that microelements act as cofactors in enzymatic reactions.

CONCLUSION

The study demonstrates that soil enzymatic activity is a sensitive and reliable indicator of soil biological condition and fertility. The highest enzyme activity is

observed in the topsoil, where organic matter and microbial biomass are concentrated.The vertical decrease in enzyme activity reflects the decline in biological processes and nutrient availability. Microelements play a crucial role in maintaining enzymatic functions, and their distribution directly affects soil biochemical activity.These findings emphasize the importance of preserving soil biological activity through sustainable management practices, including organic matter enrichment and optimized irrigation. This study demonstrates that soil enzymatic activity serves as a highly sensitive and integrative indicator of microelement dynamics and overall soil biological status in irrigated sierozem soils. The pronounced decline in enzyme activity with increasing depth reflects the reduction in organic substrates and microbial biomass, highlighting the functional stratification of soil systems. The strong correlation between enzyme activity and microelement availability confirms their synergistic role in regulating biochemical processes. These findings emphasize that maintaining topsoil quality is essential for sustaining soil fertility. Innovative approaches, including enzyme-based monitoring and optimized irrigation strategies, are crucial for enhancing soil resilience and ensuring sustainable agricultural productivity under semi-arid conditions.

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