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Ecological-Meliorative Condition and Biogeochemistry of Fallow Lands and Irrigated Soils in the Mirzachul Oasis

Masharipov Norbek Kenjabayevich[1,*], Parpiyev Gofurjon Tokhirovich[2], Oblokulov Muzaffar Rahmonkul Ugli[3]

[1]Researcher at Tashkent State Agrarian University, Lecturer at Gulistan State University, Uzbekistan
[2]Doctor of Biological Sciences (DSc), Senior Researcher Head of the Department at the National Center for Knowledge and Innovations in Agriculture, Uzbekistan
[3]Lecturer at Department of Agro-soil Science and Land Reclamation, Gulistan State University, Uzbekistan

Abstract In this article, a comparative analysis of the deposited and irrigated soils widely distributed in the Mirzachul oasis (Syrdarya region, Republic of Uzbekistan) is presented. The authors noted changes in the morphogenetic characteristics of these soils under the influence of natural and anthropogenic factors, and an assessment of their ecological-meliorative state and fertility was given. In addition, the biogeochemical features of the territory were scientifically substantiated using natural plants found in these soils, such as Karelinia caspia Pall. Less., Zygophyllum oxianum Boriss, Halimocnemis villosa Kar. & Kir), Tamarix and some cultivated agricultural crops, such as cotton (Gossipium hirsutum L.), melon (Melo bilobola L.) and wheat (Triticum durum Desf.).

Keywords Mirzachul oasis, Fallow lands, Irrigated meadow-serozem soils, Serozem-meadow soils and meadow soils, Natural plants, Cultivated agricultural crops, Ecological-meliorative state, Fertility, Biogeochemical province

1. Introduction

As the global economy continues to expand at a rapid pace, societies are facing new challenges in managing their natural resources. Soil, as a fundamental natural resource, plays a crucial role in ensuring sustainable economic growth and human well-being across all regions of the world. In order to improve environmental quality and achieve balanced growth in line with a sustainable economy, it is essential to gain a deep understanding of soils, including their properties, functions, ecological roles, and management strategies [19].

2. Analysis of Scientific Sources

Geochemistry, which today studies the history and circulation chains of elements in the Earth or in soil, continues to regard the investigation of element dynamics within the parent "rock-soil-plant" chain of both virgin and irrigated soils as a significant task. Regardless of whether the land is virgin, irrigated, rain-fed, pasture, or belongs to another category, it generally contains most of the elements found in D.I. Mendeleev's periodic table, excluding artificially synthesized ones. This is due to the fact that current analytical methods, based on available technical and technological capabilities, are not yet able to detect all natural elements present in the soil [11].

A.I. Perelman, N.S. Kasimov, M.A. Glazovskaya, V.V. Dobrovolskiy, and V.A. Kovda conducted pioneering and comprehensive research in the fields of soil chemistry, geochemistry, and soil biogeochemistry, achieving advancements through various research methodologies [13,5,4,9,2].

Biogeochemistry encompasses both biotic and abiotic reactions, incorporating organic and inorganic species. This discipline integrates marine, aquatic, terrestrial, and atmospheric sciences, ensuring continuous processes over various temporal scales [6,3].

Quantitative analysis of macro- and microelements in plants is a crucial step in determining the presence of toxic and hazardous concentrations of heavy metals that may pose a threat to living organisms. Furthermore, research on hyperaccumulator plants and their specific organs is of significant importance [11].

3. Relevance of the Topic

In recent years, numerous researchers worldwide have conducted scientific and practical studies not only on the occurrence of heavy metals in natural plants and agricultural crops but also on mitigating their toxicity and adverse effects.

* Corresponding author:
norbek2624@mail.ru (Masharipov Norbek Kenjabayevich)
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For instance, as noted by G. Yuldashev and A. Turdaliyev [20], conducting biogeochemical studies – particularly analyzing the correlation between plants and their respective soil-climatic conditions-requires assessing both the quantity and quality of elements, which is a key aspect of such research.

Thus, determining the microelement content not only in natural plants but also in agricultural crops holds significant importance. This involves assessing their concentrations in specific vegetative and generative organs, including roots, stems, leaves, buds, flowers, fruits, and seeds, which constitutes one of the key research objectives.

Based on the above considerations, our study focused on the ecological and meliorative status and biogeochemistry of the irrigated soils and fallow lands in the Mirzachul oasis, located within the arid regions of Uzbekistan.

4. Research Object and Methods

During the research conducted between 2023 and 2025 in the Khovos and Okoltin districts of the Syrdarya region, investigations were carried out on the fallow lands and irrigated soils, analyzing the processes of soil salinization, their dynamics, intensity, salt composition, accumulation, and transformation mechanisms. Additionally, biogeochemical and geochemical processes of elements were examined in natural plant species, including Karelinia caspia (Pall.) Less., Tamarix, Zygophyllum oxianum Boriss., and Halimocnemis villosa Kar. & Kir., as well as in cultivated crops such as cotton (Gossypium hirsutum L.), wheat (Triticum durum Desf.), and melon (Melo bilobola L.).

Field and soil studies were conducted using the morphogenetic and comparative-geographical methods of V.V.Dokuchaev, as well as the systematic pedogeochemical methodologies proposed by A.I. Perelman [13], G.V. Dobrovolskiy [4], M.A. Glazovskaya [5], and Alina Kabata-Pendias [8]. Chemical analyses were carried out based on standard guidelines, including the “Manual for Conducting Chemical and Agrophysical Soil Analyses for Land Monitoring” [15] and the “Guidelines for Managing Saline Soils” [16]. The chemical element analysis of soil and plant organs (roots, stems, leaves, flowers, and fruits) was performed using mass spectrometry at “Uzbekgeologiyaqidiruv” JSC. Analytical assessments and calculations utilized A.P. Vinogradov’s [2] Clarke values.

5. Research Results and Discussion

The studies conducted in the Mirzachul oasis revealed that the investigated soils belong to the “shallow” group (profile depth <50 cm) and the “moderately deep” group (profile depth 50-100 cm), according to the classification proposed by B.G. Rozanov [17], based on the thickness of the A + B genetic horizons.

The clay particle content (<0.001 mm) was found to be 0.1-2.6% in fallow lands, 0.2-3.8% in irrigated meadow-serozem soils, 3.3-10.9% in irrigated serozem-meadow soils, and 0.1-12.0% in meadow soils. The observed trend indicates a systematic increase in clay particle accumulation, demonstrating a specific pattern. Compared to fallow lands, irrigated soils exhibited a noticeable process of disaggregation, resulting in the accumulation of clay particles. This phenomenon can be directly attributed to internal weathering processes occurring within the soil.

As supporting evidence, the formation of soil layers with predominantly light to medium mechanical composition and, to some extent, heavy mechanical composition was observed in the sequence: fallow lands > irrigated meadow-serozem soils > irrigated serozem-meadow soils > irrigated meadow soils.

The level of humus content is as follows: 0.180-0.830% in fallow lands, 0.220-1.050% in irrigated meadow-serozem soils, 0.190-1.260% in meadow-serozem soils, and 0.300-1.360% in meadow soils, with a clear increase towards hydromorphic soils.

As stated in scientific sources, 90% of the nitrogen content in the soil is found in organic compounds. Therefore, the nitrogen content is closely related to the humus content. In fallow lands, the nitrogen content in the upper A_H-genetic layers is observed to be around 0.045-0.056%, in irrigated meadow-soils it ranges from 0.062-0.090%, in meadow-serozem soils it is between 0.050-0.067%, and in meadow soils it is between 0.052-0.065%. As we move towards the lower layers, it decreases to 0.022-0.050%.

The carbon-to-nitrogen ratio was observed in the ranges of 5.28-7.19; 5.28-8.79; 7.70-10.91; 10.98-15.17, while in the lower layers, it varied around 4.64-9.49. Based on this, the ecological assessment of these soils was conducted. The carbon-to-nitrogen ratio (C:N) in fallow lands, irrigated meadow-serozem, and meadow-serozem soils was classified as belonging to the “critical ecological condition” group (4-8). Meanwhile, the arable layers of irrigated meadow soils were determined to belong to the “relatively satisfactory condition” group (8-20). These findings indicate that the carbon-to-nitrogen ratio in agricultural lands of the Mirzachul oasis follows a pattern of increasing from automorphic to semi-hydromorphic to hydromorphic soils, reflecting an improvement in soil ecological conditions.

In automorphic fallow lands, the main salt component is $CaSO_4$, followed by NaCl, Na_2SO_4, and $MgCl_2$. The detected chloride salts, NaCl and $MgCl_2$, were recorded in the ranges of 0.736-7.864% and 0.047-0.411% of the total salts, respectively. The differentiation of $MgSO_4$ salts was also noted (in section 6), occurring within the range of 0.015-0.045%. The amount of toxic salts in the soil layers of fallow lands fluctuates within a broad range, comprising 21-87% of the total salt content.

Throughout the study, $CaCl_2$ salt, which has a toxicity level of 3-5, was not detected in any of the examined soils. This characteristic is a distinctive feature of these soils.

According to the analyses, NaCl salt, which has a toxicity level of 5-6, was absent in irrigated meadow-serozem, meadow-serozem, and meadow soils due to irrigated agriculture. This phenomenon is attributed to the continuous moisture conditions that displace sodium from the soil absorption complex, allowing magnesium to replace it. For example, in fallow lands, the $MgSO_4$ salts were recorded around 0.015-0.045%, while in irrigated meadow-serozem soils, the range was 0.002-0.225%, in meadow-serozem soils it was 0.009-0.175%, and finally, in meadow soils, it ranged from 0.012-0.094%. This shows an increase of 4-5 times. The ecological and ameliorative condition of fallow lands, irrigated meadow-serozem, meadow-serozem, and meadow soils was assessed based on a commonly accepted gradation scale [10,18]. The salt reserves in the 0-1 meter layer of the studied soils averaged 469.91; 183.23; 102.77; and 137.90 tons per hectare, respectively:

- Fallow lands belong to the “saline” (>300 t/ha) soil category, and their salt reserves were rated as “extremely high”. These soils are considered practically unsuitable for irrigated agriculture.
- Irrigated meadow-serozem soils belong to the “moderately saline” (150-200 t/ha) category, and their salt reserves were rated as “high”.
- Irrigated meadow-serozem soils belong to the “moderately saline” (100-150 t/ha) category, with salt reserves rated as “moderate”.
- Irrigated meadow soils belong to the “moderately saline” (100-150 t/ha) category, with salt reserves rated as “moderate”.

Analyses revealed that the Ca concentration in the fallow lands and irrigated soils, as well as in their parent materials in the Mirzachul oasis, ranged from 15,000 to 85,000 µg/L, while Na concentrations ranged from 9,600 to 52,000 µg/L. Depending on irrigation frequency, Ca was leached 3-5 times, while Mg and Na were leached up to 2-3 times. In general, the cyclic distribution of elements in soils is influenced by their Clark values, salt component quality, and mechanical composition.

The geochemical properties of macro- and microelements in automorphic, semi-hydromorphic, and hydromorphic soils were studied in terms of element migration based on geochemical research methods recommended by A.I. Perelman [13]. The concentration factor (CC) and Clark distributions (CD) of fallow lands and irrigated soils were analyzed in comparison with the Clark values for soil and lithosphere developed by A.P. Vinogradov.

The studied soils, according to the CC analysis, showed that in the plow layer (0-30 cm), cyclic elements (10^{-2}) were concentrated as follows: in fallow lands – As, Ca, Mg, K, Ni, Sr, Na, Al, B, and Zn; in irrigated meadow-serozem soils – As, Ca, K, Sr, Zn, Mg, W, P; in irrigated serozem-meadow soils – W, As, Zn, Mg; and in irrigated meadow soils – K, As, Fe, B. These elements were found to be more concentrated compared to the lithospheric Clarke values.

The sequence of the concentration Clarke of the studied chemical elements in the plow layer (0-30 cm) is as follows:

Section No. 8 – fallow land, 0-30 cm:

Cyclic elements: $$\frac{As}{4,00} > \frac{Ca}{2,87} > \frac{Mg}{2,62} > \frac{K}{1,92} > \frac{Ni}{1,48} > \frac{Sr}{1,35} > \frac{Na}{1,28} > \frac{Al}{1,20} > \frac{B}{1,08} > \frac{Zn}{1,06} > \frac{Co}{0,89} > \frac{Cu}{0,89} > \frac{P}{0,87} > \frac{W}{0,73} > \frac{Ba}{0,66} > \frac{Pb}{0,59} > \frac{Fe}{0,43} > \frac{Mo}{0,36} > \frac{Mn}{0,24};$$

Section No.1–Irrigated meadow-serozem soil, 0-35 cm:

Cyclic elements: $$\frac{As}{2,09} > \frac{Ca}{1,96} > \frac{K}{1,76} > \frac{Sr}{1,74} > \frac{Zn}{1,45} > \frac{Mg}{1,18} > \frac{W}{1,15} > \frac{P}{1,02} > \frac{Ni}{0,76} > \frac{Mo}{0,73} > \frac{Co}{0,72} > \frac{Ba}{0,69} > \frac{Cu}{0,68} > \frac{Na}{0,64} > \frac{B}{0,34} > \frac{Al}{0,31} > \frac{Fe}{0,28} > \frac{Mn}{0,24} > \frac{Pb}{0,22};$$

Section No.9–Irrigated serozem-meadow soil, 0-28 cm:

Cyclic elements: $$\frac{W}{3,08} > \frac{As}{1,64} > \frac{Zn}{1,20} > \frac{Mg}{1,12} > \frac{Fe}{0,97} > \frac{Na}{0,96} > \frac{K}{0,88} > \frac{Cu}{0,87} > \frac{P}{0,77} > \frac{Ba}{0,65} > \frac{Ca}{0,57} > \frac{Pb}{0,56} > \frac{Sr}{0,53} > \frac{Ni}{0,50} > \frac{B}{0,40} > \frac{Mo}{0,35} > \frac{Mn}{0,24} > \frac{Co}{0,21} > \frac{Al}{0,19};$$

Section No.14–Irrigated meadow soil, 0-28 cm:

Cyclic elements: $$\frac{K}{2,04} > \frac{As}{1,27} > \frac{Fe}{1,23} > \frac{B}{1,00} > \frac{Cu}{0,94} > \frac{Mg}{0,91} > \frac{P}{0,90} > \frac{W}{0,75} > \frac{Ba}{0,66} > \frac{Ca}{0,64} > \frac{Zn}{0,61} > \frac{Na}{0,60} > \frac{Ni}{0,47} > \frac{Sr}{0,47} > \frac{Mn}{0,43} > \frac{Co}{0,32} > \frac{Mo}{0,19} > \frac{Al}{0,17} > \frac{Pb}{0,16}.$$

The content of calcium (CC) in the cultivated (0-30 cm) layers of the studied soils varies between 0.51-2.87, with higher concentrations found in fallow lands (1.59-2.87) and irrigated meadow-serozem soils (1.79-2.33). In contrast, in meadow-serozem and meadow soils, the concentration ranges from 0.51-1.52, showing a decrease. It should be particularly noted that CC in meadow-serozem soils is recorded between 2.09-3.45, in serozem-meadow soils between 0.91-2.55, and in meadow soils between 1.27-1.55. The analysis of the studied soil differences revealed that the concentrations of Ca, K, Mg, Sr, and Ni are higher than the soil Clarke values. Their maximum CC values were recorded as follows: 1.49-2.87; 1.16-3.96; 1.02-2.62; 1.06-1.74; and 1.03-1.48 µg/l, respectively.

In the cultivated layers of fallow lands and irrigated soils in the Mirzachul region, the distribution of cyclic elements (CD) varies as follows:

The distribution of chemical elements in the cultivated (0-30 cm) layers according to Clarke distribution (CD) is as follows:

№8-section – fallow land, 0-30 cm:

Cyclic elements: $\frac{\text{Mn}}{4{,}17} > \frac{\text{Mo}}{2{,}75} > \frac{\text{Fe}}{2{,}33} > \frac{\text{Pb}}{1{,}68} > \frac{\text{Ba}}{1{,}51} > \frac{\text{W}}{1{,}37} > \frac{\text{P}}{1{,}15} > \frac{\text{Co}}{1{,}13} > \frac{\text{Cu}}{1{,}12} > \frac{\text{Zn}}{0{,}94} > \frac{\text{B}}{0{,}92} > \frac{\text{Al}}{0{,}83} > \frac{\text{Na}}{0{,}78} > \frac{\text{Sr}}{0{,}74} > \frac{Ni}{0{,}67} > \frac{K}{0{,}52} > \frac{\text{Mg}}{0{,}38} > \frac{\text{Ca}}{0{,}35} > \frac{As}{0{,}25}$;

№1-section–Irrigated meadow-serozem soil, 0-35 cm:

Cyclic elements: $\frac{\text{Pb}}{4{,}57} > \frac{\text{Mn}}{4{,}17} > \frac{\text{Fe}}{3{,}58} > \frac{\text{Al}}{3{,}22} > \frac{\text{B}}{2{,}93} > \frac{\text{Na}}{1{,}56} > \frac{\text{Cu}}{1{,}47} > \frac{\text{Ba}}{1{,}44} > \frac{\text{Mo, Co}}{1{,}38} > \frac{\text{Ni}}{1{,}32} > \frac{\text{P}}{0{,}98} > \frac{\text{W}}{0{,}87} > \frac{\text{Mg}}{0{,}85} > \frac{\text{Zn}}{0{,}69} > \frac{\text{Sr}}{0{,}58} > \frac{\text{Ca}}{0{,}51} > \frac{\text{K}}{0{,}49} > \frac{\text{As}}{0{,}48}$;

№9-section–Irrigated serozem-meadow soil, 0-30 cm:

Cyclic elements: $\frac{\text{Al}}{5{,}03} > \frac{\text{Co}}{4{,}86} > \frac{\text{Mn}}{4{,}17} > \frac{\text{Mo}}{2{,}89} > \frac{\text{B}}{2{,}50} > \frac{\text{Ni}}{2{,}00} > \frac{\text{Sr}}{1{,}89} > \frac{\text{Pb}}{1{,}80} > \frac{\text{Ca}}{1{,}74} > \frac{\text{Ba}}{1{,}55} > \frac{\text{P}}{1{,}29} > \frac{\text{Cu}}{1{,}15} > \frac{\text{K}}{1{,}14} > \frac{\text{Na}}{1{,}04} > \frac{\text{Fe}}{1{,}03} > \frac{\text{Mg}}{0{,}89} > \frac{\text{Zn}}{0{,}83} > \frac{\text{As}}{0{,}61} > \frac{\text{W}}{0{,}33}$;

№14-section–Irrigated meadow soil, 0-28 cm:

Cyclic elements: $\frac{\text{Pb}}{6{,}40} > \frac{\text{Al}}{5{,}75} > \frac{\text{Mo}}{5{,}20} > \frac{\text{Co}}{3{,}10} > \frac{\text{Mn}}{2{,}33} > \frac{\text{Ni}}{2{,}15} > \frac{\text{Sr}}{2{,}13} > \frac{\text{Na}}{1{,}67} > \frac{\text{Zn}}{1{,}63} > \frac{\text{Ca}}{1{,}56} > \frac{\text{Ba}}{1{,}51} > \frac{\text{W}}{1{,}33} > \frac{\text{P}}{1{,}11} > \frac{\text{Mg}}{1{,}10} > \frac{\text{Cu}}{1{,}07} > \frac{\text{B}}{1{,}00} > \frac{\text{Fe}}{0{,}82} > \frac{\text{As}}{0{,}79} > \frac{\text{K}}{0{,}49}$;

The final result of the migration process of elements in the soil is their distribution and accumulation [1]. Radial migration, i.e., eluvial-accumulation coefficients, is an indicator characterizing the migration of chemical elements within the soil profile. These coefficients describe the accumulation or movement of elements in a specific soil-genetic horizon compared to the initial soil-forming rocks. Radial differentiation allows us to gain a particular understanding of the redistribution of biogeochemical elements within the soil profile and the landscape as a whole [22,7].

The radial differentiation coefficient (CR) in the A and B1 layers of fallow lands ranges between 1.05 and 2.94. The CR values for different elements in various soil types are as follows: in fallow lands, the sequence is B>Fe>Ca> Mo>Pb>Mn>Ni>As>K>Sr>Co>Zn>Cu>Ba>Al>W>Na>P; in irrigated meadow-serozem soils, it is Zn>Al>Na>Sr> Mo>P>Ba>K; in meadow-serozem soils, it is Pb>Zn; and in meadow soils, it is K>W>Mn>Ba>Cu>B>P>Al. This shows the accumulation pattern of these elements. It is important to note that, depending on hydromorphic processes, the radial differentiation coefficient (CR) is lower in meadow-serozem and meadow soils, which has been proven. In these soils, a higher concentration of most cyclic elements is observed in the upper layers. This phenomenon can be explained by the association of these elements with organic matter, plant and animal metabolism, and the low mobility of the studied soils in a weakly alkaline environment.

It is known that an element classified as a microelement for one plant species may accumulate in significant amounts in another plant species or its organs. Furthermore, many chemical elements that are found in macro quantities in soil and considered macroelements from a geological perspective can appear as microelements in plant tissues.

In our research, the elemental chemical composition of natural plants and agricultural crops was analyzed based on cyclic, dispersed, rare, noble metal, and radioactive element groups.

As illustrated in Figures 1, 2, 3, and 4, the amount of molybdenum (Mo) in the aerial parts of natural plants such as Karelinia caspia (Pall.) Less., Zygophyllum oxianum Boriss, Halimocnemis villosa Kar. & Kir., and Tamarix is approximately 10 to 76 times higher than other elements. In irrigated soils, biogeochemical provinces rich in molybdenum and boron were identified in cultivated crops, including:

- Cotton (Gossypium hirsutum L.): Mo – 8.571-76.190 mg/kg; B – 1.786-6.310 mg/kg.
- Melon (Melo bilobola L.): Mo – 1.000-4.211 mg/kg; B – 1.994-15.278 mg/kg.
- Wheat (Triticum durum Desf.): Mo – 1.500-2.875 mg/kg; B – 0.873-3.789 mg/kg.

The elements Sr, Zn, and Cu were also found in significant amounts in almost all organs of the studied natural and cultivated plants. This phenomenon can also be observed in the concentrations of sodium (Na) and aluminum (Al) microelements in the aboveground parts of the studied natural plants. Specifically, the sodium content was recorded as follows: Tamarix – 0.719 mg/kg, Zygophyllum oxianum – 0.906 mg/kg, Karelinia caspia – 0.969 mg/kg, and Halimocnemis villosa – 2.813 mg/kg, indicating that sodium accumulates more than other elements (Figures 1, 2, 3, 4).

Molybdenum (Mo) was found to accumulate more in agricultural crops, particularly in the roots, flowers, bolls, and leaves of cotton; the leaves, flowers, roots, and stems of melons; and the stems, leaves, and roots of wheat.

Overall, compared to natural plants, cotton absorbs 7.4 to 17.0 times more macro- and microelements from the soil in its roots, stems, leaves, flowers, and bolls. Among these, cotton leaves showed a high capacity to absorb and accumulate molybdenum, with an uptake rate of 76.2% relative to its soil content, demonstrating characteristics of a molybdenum hyperaccumulator. In natural plants, this property was observed in Halimocnemis villosa, with 4.50% molybdenum accumulation in its aboveground parts, and in melon stems, with 4.21% accumulation.

Similarly, in terms of bor hyperaccumulation, melon stems and flowers showed accumulation rates of 15.28%, while cotton flowers (6.31%) and bolls (5.96%) also exhibited significant accumulation. These variations in elemental concentrations across different plant species depend on the characteristics of the soil in which they grow and environmental factors (Figures 1, 2, 3, 4).

Some plant species can survive and reproduce in metalliferous soils, exhibiting a high tolerance (i.e., hypertolerance) to the typically toxic concentrations of heavy metals in their growth substrate. From this perspective, hypertolerance in plants can manifest through two contrasting mechanisms. On the one hand, certain plant species exclude the uptake of toxic metals, thereby limiting their entry into physiological concentrations and restricting their absorption from the roots [21].

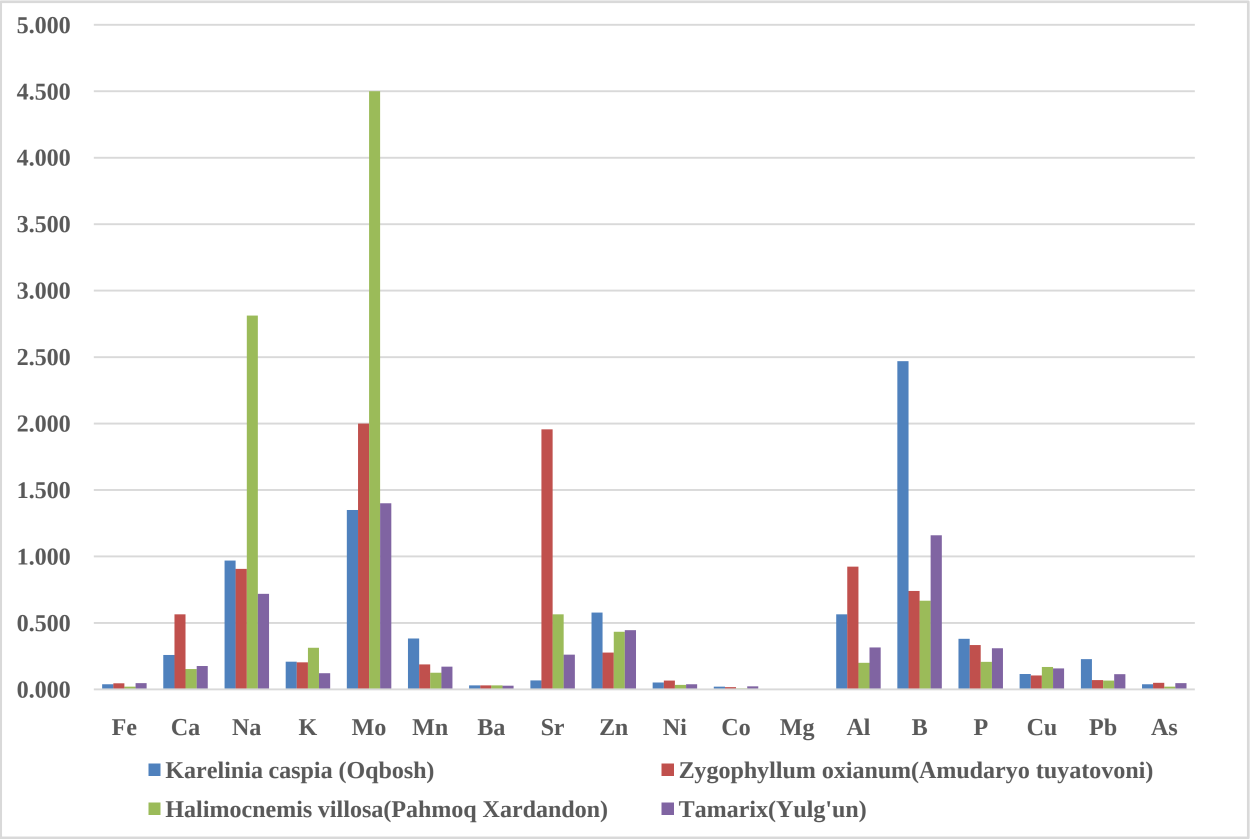

Figure 1. Biological absorption coefficient of biomicroelements in the aboveground organs of Karelinia caspia (Pall.) Less., Zygophyllum oxianum Boriss, Halimocnemis villosa Kar. & Kir., and Tamarix (measured in g/t)

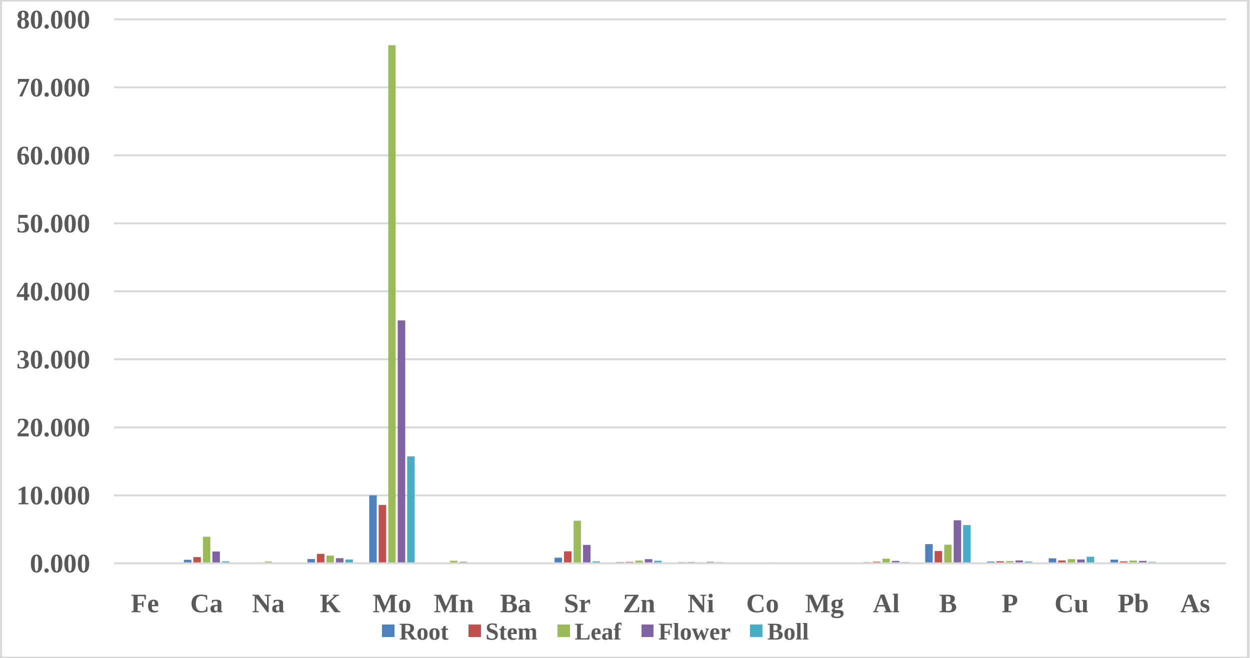

Figure 2. The biological absorption coefficient of biomicroelements in the organs of cotton (Gossypium hirsutum L.) (measured in g/t)

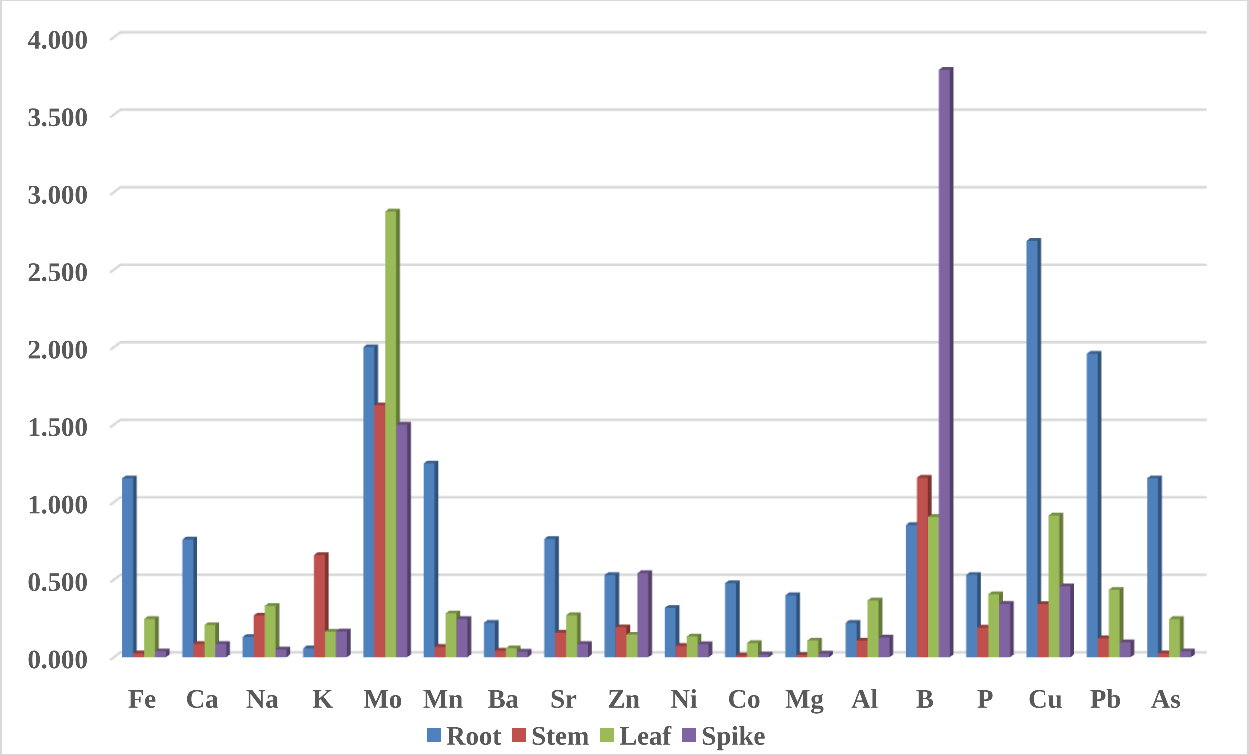

Figure 3. The Biological Absorption Coefficient of Biomicroelements in the Organs of Wheat (Triticum durum Desf.) (g/t basis)

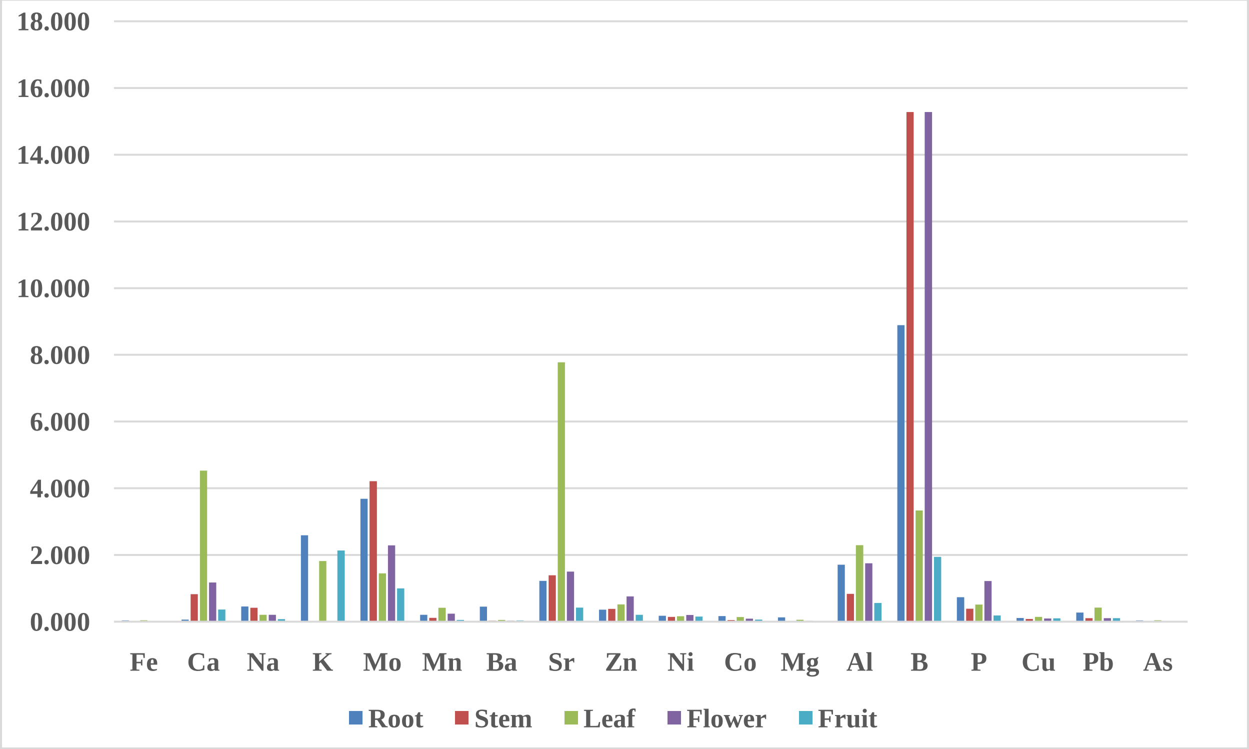

Figure 4. The biological absorption coefficient of biomicroelements in the organs of the melon plant (Melo bilobola L.) (in g/t)

To assess the ability of living organisms to absorb and accumulate elements, the intensity of element absorption (Ax) was proposed as a biogeochemical indicator by B.B. Polynov [14]. Academician A.I. Perelman later introduced this indicator to science as the biological absorption coefficient.

According to the methodology proposed by A.I. Perelman, if the absorption of elements by plants is such that Ax < 1, the element is considered to be retained rather than accumulated. The most important generalized indicator of the intensity of an element's biogenic migration is its bioaffinity (B), which is determined by comparing the element's Clarke concentration in living organisms to its Clarke value in the lithosphere or soil [13]. In general, it is important to acknowledge the relative nature of these indicators.

We studied the elemental composition of natural and cultivated plants based on the soil compositions in which they naturally grow or are cultivated [12].

In natural plant species growing in fallow lands, the biological absorption coefficient of heavy metals follows a decreasing order. In Karelinia caspia (Pall.) Less., it follows Zn > Br > Mn > Cr > Co > Fe > Ba; in Zygophyllum oxianum Boriss., Halimocnemis villosa Kar. & Kir., and Tamarix species, it follows Br > Zn > Co > Cr > Mn > Ba > Fe.

Controlling the concentration of chemical elements in soils, particularly in reducing contamination levels of heavy metals and natural radionuclides, allows for the application of the geochemical characteristics of studied natural plant species and agricultural crops (such as cotton, wheat, and melon) in agro-meliorative, specifically phyto-meliorative, measures. These findings can be utilized in the appropriate placement of plant species to enhance soil remediation strategies.

The studies analyzed the biological absorption capacity of molybdenum (Mo), zinc (Zn), cobalt (Co), and manganese (Mn) by natural plant species (Karelinia caspia, Zygophyllum oxianum, Halimocnemis villosa, and Tamarix) as well as agricultural crops (cotton, wheat, and melon). Based on the biological absorption coefficients of these microelements, it was determined that the organs of cotton (Gossypium hirsutum L.) belong to the “highly accumulating” (10-100) category for Mo.

For phosphorus (P), among agricultural crops, the organs of melon (Melo bilobola L.) were classified as “strongly accumulating” (5-10).

The research also revealed that specific biogeochemical processes have developed not only in fallow lands but also in irrigated meadow-serozem, serozem-meadow, and meadow soils.

For instance, in fallow lands, Karelinia caspia (Pall.) Less., Zygophyllum oxianum Boriss, Halimocnemis villosa Kar. & Kir., and Tamarix species were found to be biologically accumulative (Ax > 1) and categorized as “weakly accumulating” (1–5). In all cases, Mo exhibited dominance, while these natural plants also accumulated P, Na, and Sr [12].

In irrigated meadow-serozem soils, wheat (Triticum durum Desf.) was found to accumulate Mo, P, and Pb. In serozem-meadow soils, melon (Melo bilobola L.) accumulated Mo, Ca, K, Sr, and B, while in meadow soils, cotton (Gossypium hirsutum L.) accumulated Mo, Ca, Sr, and P. These crops were classified as “weakly accumulating” (Ax > 1, 1–5 category). This phenomenon, in our opinion, can be directly attributed to the impact of irrigated agriculture compared to fallow lands.

6. Conclusions, Recommendations, and Suggestions

1. In the Mirzacho‘l oasis, based on the thickness of the A + B genetic horizons, the studied soils were classified as “thin” (profile < 50 cm) and “moderately thick” (profile 50-100 cm), depending on the agricultural practices applied.
2. Under the influence of irrigation, the clay fraction (<0.001 mm) follows a specific pattern: in fallow lands, it ranges from 0.1% to 2.6%; in irrigated meadow-serozem soils, from 0.2% to 3.8%; in irrigated serozem-meadow soils, from 3.3% to 10.9%; and in meadow soils, from 0.1% to 12.0%. This increase indicates the occurrence of a disaggregation process in irrigated soils compared to non-irrigated fallow lands.
3. The level of humus content varies as follows: in fallow lands – 0.180-0.830%, in irrigated meadow-serozem soils – 0.220-1.050%, in serozem-meadow soils – 0.190-1.260%, and in meadow soils – 0.300-1.360%. This increase towards hydromorphic soils indicates the improvement of soil ecological conditions, as evidenced by the carbon-to-nitrogen ratio, which follows the pattern: automorphic > semi-hydromorphic > hydromorphic soils.
4. The study confirms that the nutrient (NPK) content in the examined soils is directly influenced by both natural factors and human agricultural activities.
5. From a soil-reclamation perspective, irrigated soils are agroecologically suitable for agricultural crop cultivation. The studied fallow lands belong to the “saline” (>300 t/ha) category, where salt reserves are classified as “extremely high”, rendering them almost unsuitable for irrigated farming. To rehabilitate degraded lands, it is recommended to plant halophytic species such as Karelinia caspia (Pall.) Less., Zygophyllum oxianum Boriss, and Halimocnemis villosa Kar. & Kir. for the development of green cover and as a supplementary fodder source for livestock.
6. Fallow lands and irrigated soils exhibit weak bioaccumulation (Ax > 1) and fall into the very weak (Ax < 0.1), weak (Ax = 0.01-0.1), and moderate (Ax = 0.1-1) retention categories based on the biological absorption coefficient of microelements. The biogeochemical activity (BCA) index for naturally occurring plants in serozem soils is as follows: Tamarix – 5.97, Karelinia caspia – 8.38, Zygophyllum oxianum – 9.20, and Halimocnemis villosa – 10.76. Among agricultural crops, wheat (Triticum durum Desf.) has a BCA of 10.35, melon (Melo bilobola L.) – 21.47, and cotton (Gossypium hirsutum L.) – 40.87.
7. In characterizing the fallow lands and irrigated meadow-serozem, serozem-meadow, and meadow soils of the Mirzacho‘l oasis, the background levels of cyclic elements (Fe, Ca, Na, K, Mo, Mn, Ba, Sr, Cr, Zn, Ni, Co, Mg, Al, B, P, Cu, Pb, As, W), dispersed elements (Rb, Cs, Ga, Li), and radioactive elements (U)

play a significant role. The background concentration of these elements serves as a basis for geochemical and biogeochemical soil characterization, soil-geochemical and soil-ecological monitoring, the selection and appropriate placement of high-yielding agricultural crops, and the production of environmentally friendly agricultural products.

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