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Biogeochemistry of Sandy Desert Soils in the Bukhara Oasis and the Sparse-Leaved Yantok (Alhagi sparsifolia) Plant (A Case Study of Shofirkon District)

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Abstract

This study investigated the distribution characteristics of macroelements (Na, K, Ca) in the stem, leaves, and seeds of the sparse-leaved yantok (*Alhagi sparsifolia*) plant growing in sandy desert soils. The research findings revealed the selective accumulation of elements within plant tissues and identified potassium as the dominant element accumulated across all organs. In particular, the high concentration of potassium in generative organs is explained by the plant's metabolic activity and reproductive stability. The predominant accumulation of sodium in the leaves indicates the presence of an adaptive mechanism that maintains osmotic balance through the deposition of ions in vegetative tissues. The relatively low calcium content is associated with its limited bioavailability in sandy soils. The bioaccumulation of the studied elements followed the sequence K > Na > Ca, reflecting the selective mineral nutrition strategy of the sparse-leaved yantok adapted to arid environments. The obtained results suggest that this plant can serve as an important bioindicator for assessing macroelement migration in desert ecosystems and provide a scientific basis for a deeper understanding of biogeochemical processes within the soil–plant system.

Keywords: macroelements, bioaccumulation, sandy desert soils, biogeochemical processes, element migration, bioindicator plants.

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1 Introduction

Soil–plant systems formed in desert and semi-desert regions are directly related to issues of ecological stability, food security, and the rational use of natural resources on a global scale. In this respect, the Bukhara oasis, located in Central Asia, has particular scientific and practical significance, distinguished by its natural–geographical conditions, the combination of irrigated and natural sandy desert soils, and its specific vegetation cover. In particular, the biogeochemical characteristics of sandy desert soils and natural vegetation formed in the territories of the Gijduvon, Shofirkon, and Peshku districts have not yet been sufficiently studied in a systematic and comprehensive manner.

Scientific studies conducted on the soil–climatic conditions and irrigation processes of the Bukhara oasis represent one of the important directions of regional soil science. By assessing the soil–climatic conditions of irrigated lands in the Bukhara oasis, it has been shown that irrigation leads to significant changes in the physical and chemical properties of soils [1]. This work serves as an important source for understanding soils of the oasis under anthropogenic influence.

By analyzing the biodiagnostic indicators of irrigated soils, it has been determined that the biological activity and fertility of soils are closely related to the irrigation regime. These results are of considerable importance for evaluating the differences between natural and cultivated landscapes [2].

The formation and evolution of irrigated soils in the Gijduvon district have been investigated, and it has been scientifically substantiated that the soil cover undergoes morphological and chemical transformations under the long-term influence of irrigation. These studies provide an important methodological basis for comparing irrigated soils with natural sandy desert soils [3, 7].

The historical and territorial development of the water management system in the Bukhara oasis has been analyzed, demonstrating that the distribution of water resources directly affects soil–geochemical processes. This factor represents an important background condition for biogeochemical research [4].

The granulometric composition of irrigated soils in the Bukhara region has been studied, emphasizing the role of mechanical composition in the migration of chemical elements. These conclusions are of significant importance for assessing the mobility of chemical elements in sandy desert soils [5].

The interrelationships between geosystems and their components in the Bukhara region have been analyzed, substantiating the necessity of considering the soil–plant–water system as an integrated geosystem [6].

At the international level, studies conducted by Kabata-Pendias and Pendias [8] and Alloway [9] on soil and plant biogeochemistry are of fundamental importance. These works comprehensively describe the circulation of microelements in soils and plants, bioaccumulation processes, and ecological risks, and their approaches can be applied under the conditions of the Bukhara oasis.

The biogeochemical characteristics of plants in arid regions have been investigated, and it has been scientifically substantiated that desert plants possess the ability to intensively accumulate biologically active elements under stress conditions [10]. This approach is of considerable importance for the analysis of natural vegetation in the Bukhara oasis.

The natural vegetation cover of the Bukhara oasis has been ecologically characterized, demonstrating the spatial distribution of plant species and their adaptive features to environmental conditions [11]. The biogeochemical relationships within the soil–plant system in the sandy desert regions of Uzbekistan have been analyzed, identifying the patterns of element migration and bioaccumulation [12].

The concept of soil-forming factors developed by Jenny constitutes the theoretical and methodological basis of this study [13]. The agroecological and biogeochemical status of sandy soils in the Gijduvon, Shofirkon, and Peshku districts has been assessed, scientifically revealing their regional characteristics [14–18].

In general, the available literature provides important scientific information on soils and vegetation in the Bukhara oasis; however, the biogeochemical system of sandy desert soils and natural vegetation has not been sufficiently studied within a comprehensive and integrated framework. This study is aimed at addressing this scientific gap.

2 Research Object and Methods

The research object of this study was sandy desert soils and the medicinal plant sparse-leaved camelthorn (Alhagi sparsifolia) distributed within the territory of the "Mirzo Jamshid" farm located in the Osiyo massif of Shofirkon district, Bukhara region.

As the main research method, soil profiles were taken using the profile and morphogenetic methods developed by V.V. Dokuchaev. Elemental analysis of soil and anzur onion samples was conducted using the neutron activation method at the Laboratory of Ecology and Biotechnology of the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan. In this procedure, the samples were irradiated in an atomic reactor with a neutron flux of 5×10^{13} $\mathrm{neutrons/cm^2 \cdot s}$, and the concentrations of chemical elements were determined based on their half-life periods.

3 Research Results

The sandy desert soils widely distributed in the territory of the "Mirzo Jamshid" farm located in the

Osiyo massif of Shofirkon district, Bukhara region, as well as the medicinal semi-shrub sparse-leaved camelthorn (Alhagi sparsifolia), which is adapted to these edaphic conditions, were selected as the objects of this study. This plant belongs to the Fabaceae family and is considered one of the typical xerophytic representatives of arid regions. It is distinguished by its deep root system, high ecological adaptability, and bioaccumulative properties.

The study areas are geologically composed of alluvial–proluvial deposits, and the soil cover mainly consists of sandy and sandy loam fractions. A sharply continental climate prevails in the region: air temperatures are high in summer, precipitation is low, and evaporation occurs intensively. Such conditions directly influence the migration and concentration of chemical elements in the soil.

Under the climatic conditions of the Bukhara oasis, the quantitative composition of elements in sandy soils plays an important role in plant growth and development. If significant changes in the amount of chemical elements, particularly bioelements, occur in the soil, their effects are immediately reflected in plants. However, when these elements occur in soils at the macro-, micro-, or ultramicroelement level, their presence may not always be immediately noticeable in the external or internal characteristics of plants. Moreover, the assimilated elements may accumulate in different parts of the plant body. These factors play an important role in the biological, biogeochemical, and other characteristics of organisms, particularly agricultural plants.

From this perspective, it can be noted that if the accumulation of chemical elements in the studied sparse-leaved camelthorn (Alhagi sparsifolia) is observed mainly in the aboveground organs, such plants are classified as belonging to the acropetal group, whereas if chemical elements accumulate predominantly in the underground parts, such plants are classified as belonging to the basipetal group. Based on these considerations, the contents of macroelements in Alhagi sparsifolia growing under sandy desert soil conditions are presented in Table 1.

According to the data presented in the table, the study of macroelement distribution in sparse-leaved camelthorn (Alhagi sparsifolia) growing on sandy desert soils of the Osiyo massif in Shofirkon district provides an opportunity to assess biogeochemical processes within the soil–plant system. The results of the study revealed that the elements Na, K, and Ca accumulate in different concentrations in the soil and plant organs.

Table 1. Macroelements content in sparse-leaved camelthorn (Alhagi sparsifolia) growing on sandy desert soils of the "Mirzo Jamshid" farm in the Osiyo massif of Shofirkon district, mg/kg (n=2)

Elements	Soil	Sparse-leaved camelthorn (Alhagi sparsifolia)		
	0–10 cm	Stem	Leaf	Seed
Na	220	145	605	201
K	402	540	1250	1450
Ca	115	0.60	4.2	4.5

According to the distribution of sodium (Na), its content in the 0–10 cm soil layer was 220 mg/kg. This indicator reflects a relatively moderate level of salinity typical of sandy desert soils. The distribution of sodium within plant organs was uneven, with the highest concentration recorded in the leaves at 605 mg/kg. In the stem, this value was 145 mg/kg, while in the seeds it was 201 mg/kg.

The high concentration of sodium in the leaves can be explained by the halophytic characteristics of camelthorn. Desert plants often regulate cellular osmotic pressure by accumulating excess salts in vegetative organs, particularly in the leaves. This mechanism helps the plant maintain water balance under arid and saline conditions. The relatively low content of sodium (Na) in the stem indicates the presence of selectivity in transport processes. The limited amount of sodium in seeds can be considered a physiological adaptation aimed at protecting reproductive organs from salt stress.

Migration and bioaccumulation of potassium (K). While the potassium content in the soil was determined to be 402 mg/kg, a significantly higher accumulation of this element was observed in plant organs. Potassium content reached 540 mg/kg in the stem, 1250 mg/kg in the leaves, and 1450 mg/kg in the seeds.

This situation indicates that camelthorn is a plant capable of actively absorbing potassium. The particularly high concentration of potassium in seeds is associated with its important physiological functions, including the activation of enzymatic processes, the support of protein synthesis, and the maintenance of osmotic balance.

The intensive transfer of potassium from soil to plant indicates a high bioaccumulation coefficient. This allows sparse-leaved camelthorn to be classified among bioindicator plants that reflect potassium as an indicator element.

Assimilation characteristics of calcium (Ca). Although the calcium content in the soil was 115 mg/kg, its concentration in plant organs was recorded at a considerably lower level: 0.60 mg/kg in the stem, 4.2 mg/kg in the leaves, and 4.5 mg/kg in the seeds.

This situation can be explained by several geochemical factors:

1. In sandy soils, calcium often occurs in carbonate form and is relatively immobile for plant uptake.

2. An alkaline environment reduces the solubility of calcium.

3. Calcium transport within the plant organism proceeds relatively slowly.

Nevertheless, the relatively higher concentration of calcium in leaves and seeds compared to the stem indicates its important role in strengthening cell walls and supporting the development of generative organs.

The analyses showed that the transfer of elements from soil to plant depends on their chemical properties, the mechanical composition of the soil, and the degree of development of the root system.

The deep root system of sparse-leaved camelthorn enables the plant to absorb mineral substances even under low moisture conditions, to uptake elements from deeper soil layers, and to actively participate in biogeochemical cycling.

Based on the obtained results, the intensity of element bioaccumulation follows the sequence: K > Na > Ca. This indicates that camelthorn is a plant that actively accumulates potassium, is tolerant to sodium, and exhibits selective uptake with respect to calcium.

The obtained data once again confirm the high level of adaptation of sparse-leaved camelthorn to desert environments. In particular, the accumulation of sodium in the leaves indicates tolerance to salt stress; the high potassium content reflects metabolic activity; and the limited uptake of calcium represents an adaptive response associated with the chemical conditions of the soil.

Such characteristics allow this plant to be considered an important phytocomponent ensuring the biogeochemical stability of desert landscapes.

Scientific and practical significance of the research results. The obtained results make it possible to formulate the following scientific conclusions: sparse-leaved camelthorn selectively absorbs macroelements; the mobility of elements in sandy desert soils is relatively high; and the plant can serve as an indicator of geochemical processes occurring in the soil. From a practical perspective, these findings provide an important scientific basis for ecological monitoring of desert areas, assessment of the mineral composition of medicinal plant raw materials, and identification of land degradation processes.

According to the results of the macroelement spectrum in the 0–10 cm layer of sandy desert soils, significant differences in the concentrations of elements were identified. Graphical analysis indicates that potassium (402 mg/kg) is the dominant element, confirming its higher concentration compared with sodium (220 mg/kg) and calcium (115 mg/kg). This situation reflects the uneven distribution of mineral reserves in sandy soils and indicates that geochemical processes exhibit a selective character.

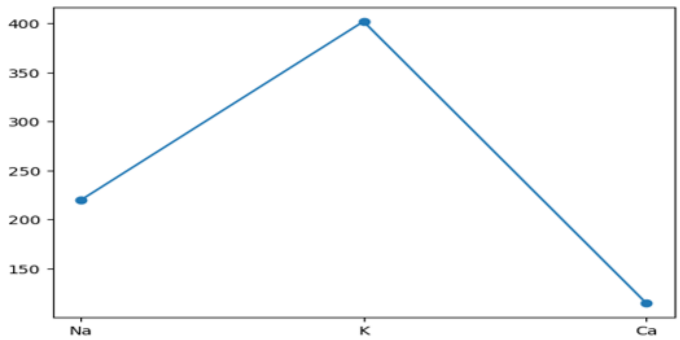

Figure 1. Distribution dynamics of Na, K, and Ca elements in the 0–10 cm layer of sandy desert soils in the Osiyo massif of Shofirkon district

The high potassium content indicates the presence of a potential nutrient reserve in the soil, as potassium plays an important role in regulating enzymatic processes, water exchange, and osmotic balance in plants. Therefore, plants growing in the study area, particularly sparse-leaved camelthorn (Alhagi sparsifolia), are likely to actively absorb this element.

The moderate level of sodium indicates that the soils are not strongly saline; however, ion migration processes are active. The high intensity of evaporation typical of desert landscapes may lead to the accumulation of sodium in the upper soil layers. This creates a geochemical basis for the development of salt-adaptation mechanisms in plants growing in the region.

The relatively low content of calcium may be associated with its immobilized state within carbonate minerals or with leaching processes resulting from the sandy mechanical composition of the soil. The low concentration of calcium may limit the buffering capacity of the soil and potentially affect the bioavailability of certain nutrient elements.

In general, the macroelement spectrum follows the sequence K > Na > Ca, indicating the presence of geochemical differentiation in sandy desert soils. These results confirm that the mineral composition of the soil is an important factor shaping the nutritional strategies of regional vegetation and scientifically substantiate the biogeochemical relationships within the soil–plant system. The spectrum of macroelement distribution in sparse-leaved camelthorn (Alhagi sparsifolia) demonstrated significant differences among various plant organs. The highest concentrations of potassium detected in all organs, particularly in seeds and leaves, confirm its important role in metabolic processes, enzymatic activity, and generative development. The accumulation of sodium mainly in the leaves indicates the plant's adaptation to arid and saline environments, as well as the presence of mechanisms that maintain osmotic balance through the accumulation of ions in vegetative tissues.

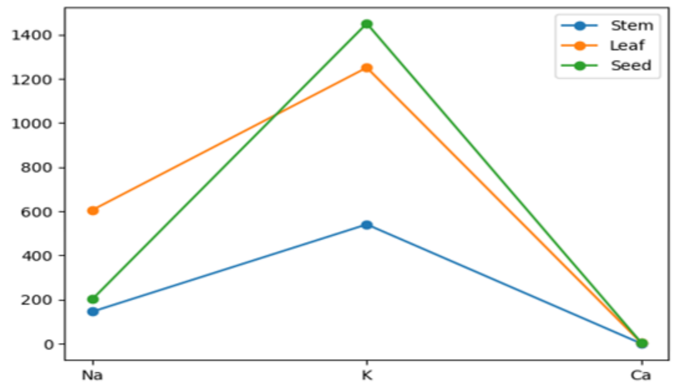

Figure 2. Spectrum reflecting the distribution of Na, K, and Ca macroelements in the stem, leaf, and seed organs of sparse-leaved camelthorn (Alhagi sparsifolia)

The relatively low concentration of calcium in all organs can be explained by its limited bioavailability in sandy soils. The accumulation of elements follows the sequence K > Na > Ca, reflecting the plant's selective mineral nutrition strategy. The obtained results indicate that sparse-leaved camelthorn is highly adapted to desert ecosystems and can be used as a bioindicator for assessing macroelement migration.

The distribution of macroelements in sparse-leaved camelthorn (Alhagi sparsifolia) growing in the sandy desert soils of Shofirkon district demonstrates the presence of active biogeochemical exchange within the soil–plant system. The plant's intensive accumulation of potassium, tolerance to sodium, and limited uptake of calcium reflect its ecological adaptation strategy to arid environments. These findings contribute to a deeper understanding of element cycling in desert ecosystems and support the development of bioindication studies.

4 Conclusion

The distribution of macroelements in sparse-leaved camelthorn (Alhagi sparsifolia) growing on the sandy desert soils of Shofirkon district confirmed the presence of selective biogeochemical exchange within the soil–plant system. The accumulation of potassium in plant organs several times higher than in the soil indicates its high bioaccumulative potential, while the increased concentration in generative organs reflects the intensity of metabolic and reproductive processes.

The high accumulation of sodium in the leaves indicates that Alhagi sparsifolia is a xerohalophytic species adapted to salt stress, whereas the low uptake of calcium can be explained by the limited availability of its bioavailable forms in the soil. The bioaccumulation of elements follows the sequence K > Na > Ca, reflecting the plant's mineral nutrition strategy adapted to arid environments.

These results provide a scientific basis for evaluating sparse-leaved camelthorn as an important bioindicator of macroelement migration in desert ecosystems and contribute to a deeper understanding of biogeochemical processes within the soil–plant system.

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