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Soil morphological and physico-chemical characteristics of *Zygophyllum fabago* L. populations in the Ili-Balkhash Region of Kazakhstan

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Abstract
The present study investigates the morphological, physical, and chemical properties of soils in natural habitats of *Zygophyllum fabago* L. across three ecologically distinct populations in the Ile-Balkhash region of Kazakhstan. Soil samples were collected in August–September 2024 near Topar, Bakanas, and Miyaly villages, representing desert sandy and alluvial environments. Standard field profile descriptions and laboratory analyses were conducted following national GOST and classical pedological methods. Soils in all sites were characterized as weakly humus sandy or loamy sands with alkaline pH levels (8.4–8.9) and low organic carbon content (0.24–1.08%). Granulometric composition varied from sandy (Pop. 1) to loamy sand (Pop. 2 and 3), with moisture contents ranging from 3.9% to 7.6%. Mobile nutrients were present in low to moderate quantities, with potassium being relatively higher in Pop. 3. Heavy metals (Zn, Cu, Pb) were within permissible limits across all sites; however, cadmium (Cd) exceeded thresholds in total forms in Populations 2 and 3. Salt analysis revealed non-saline to moderately saline conditions, with increased salinity in surface horizons of Population 3. The results provide important baseline data for understanding the ecological amplitude of *Z.fabago* and assessing soil-plant interactions in arid ecosystems of Central Asia.

Keywords: *Zygophyllum fabago L., soil morphology, granulometric composition, heavy metals, salinity, Kazakhstan.*

Introduction

The Ile-Balkhash region, located in southeastern Kazakhstan, encompasses a diverse array of landscapes, including the Ili River delta, Lake Balkhash, and adjacent desert and semi-desert areas (Chen et al, 2013). This region is characterized by its arid to semi-arid climate, with annual precipitation ranging from 100 to 300 mm, and high evaporation rates exceeding precipitation, leading to significant soil salinization issues (Aizen et al, 2007; Bernauer et al, 2012). The prevalence of saline soils, particularly Solonchaks, poses challenges for agriculture and ecosystem sustai-nability (Demin et al, 2016). Soil salinization in Central Asia, including the Ili-Balkhash basin, has been exacerbated by both natural factors and anthropogenic activities (Karthe et al, 2018). Inefficient irrigation practices and poor drainage systems have led to the accumulation of salts in the soil profile, degrading soil structure and fertility

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(Unger-Shayesteh, 2013). Appro-ximately 33% of irrigated lands in Kazakhstan are affected by salinize-tion, impacting crop yields and food security (Yu et al, 2019; Lioubimtseva et al, 2009). In this article, halophytic plant species such as *Zygophyllum fabago* L. play a crucial role in stabilizing saline soils and maintaining ecological balance (Flowers et.al., 2015). *Z.fabago* is a perennial herbaceous plant known for its tolerance to high salinity and drought conditions (Gemejieva, 2022). It is widely distributed across arid and semi-arid regions of Central Asia and has been utilized in land reclamation and soil stabilization efforts (Breckle et al, 2012). Despite its ecological significance, there is a paucity of comprehensive studies examining the soil characteristics of *Z. fabago* habitats in the Ili-Balkhash region. Understanding the morphological, chemical, and physical properties of soils supporting *Z.fabago* populations is essential for informing land management and restoration strategies in saline environments. This study aims to investigate the soil properties associated with natural populations of *Z.fabago* in the Balkhash district of Kazakhstan. Specifically, we analyze soil morphology, granulometric composition, organic matter content, pH, salinity levels, and con-centrations of macro- and micronutrients. By eluci-dating the soil conditions favorable to *Z. fabago*, effective management of salt-affected soils and the maintenance of halophytic vegetation in arid regions will be possible.

Materials and Methods

Research area

In Table 1 location of study area.

Table 1. *Locations and elevations of studied populations in the Ile-Balkhash Region*

N°	Location	Altitude (m als)	Geographical coordinates
Population 1	Near Topar village, Balkhash district, the Ili River delta	362	45.05190519 N 75.00765995 E
Population 2	Near Bakanas village, Balkhash district	389	44.91989194 N 75.98281400 E
Population 3	Near Miyaly village, Balkhash district.	420	44.50729833 N 76.74105177 E

Relief

The Ili-Balkhash basin, situated in southeastern Kazakhstan, encompasses a diverse range of geomorphological features (Mukhitdinov et.al., 2020). The region includes the Dzungarian Alatau and Chu-Ili mountain ranges to the south and southeast, which contribute to the sediment load of the Ili River and influence local microclimates (Koroleva et al., 2019). The central part of the basin is characterized by exten-sive alluvial plains formed by the Ili River and its tributaries, featuring a network of river channels, oxbow lakes, and wetlands, particularly prominent in the Ili River delta (Guo et al, 2015). To the north and west, the terrain transitions into arid zones, including the Saryesik-Atyrau and Taukum deserts, marked by sand dunes and sparse vegetation (Guo et al, 2014). These geomorphological featu°res play a crucial role in the region's hydrology and soil formation processes. The varying elevations and landforms influence water flow, sediment deposition, and the distribution of soil types, which are essential factors for vegetation patterns and land use (Huang et al., 2022).

Climatic Conditions

The Ili-Balkhash region experiences a sharply continental and arid climate, characterized by significant temperature fluctuations and low precipitation (Starodubtsev et.al., 2024). Average annual temperatures range from -14°C in January to 24°C in July, with extremes reaching -30°C in winter and 40°C in summer. Annual precipitation varies across the basin, from less than 150 mm in the arid lowlands to approximately 800 mm in the mountainous areas (Myrzakhmetov et al, 2022). High evaporation rates, exceeding 950 mm annually, contribute to the region's aridity and influence soil salinization processes (Talipova et.al, 2021). These climatic conditions significantly impact the hydrological regime of the Ili River and Lake Balkhash, affecting water availability, soil moisture, and the overall ecological balance of the region.

Field Survey and Laboratory Methods

Field surveys were conducted from August to September 2024 across three populations of *Zygophyllum fabago* L. in the Ile-Balkhash region of Almaty Province, Kazakhstan. At each site, representative soil profiles were excavated to depths of 90–95 cm using the key transect method. In morphological descriptions included horizon depth, color, structure, compaction, carbonate reaction, and root density, following Rozanov (2004) and Korolyuk (2012). Soil samples from each horizon were collected and analyzed in the Laboratory

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of the Kazakh Research Institute of Soil Science and Agrochemistry named after U.U.Uspanov (Almaty, Kazakhstan). Laboratory analyses assessed the physical and chemical properties of soils in accordance with national and international standards. Soil moisture content was determined gravimetrically using aluminum containers. Samples from each horizon were weighed, oven-dried at 105 °C for 5 hours, cooled in a desiccator, and reweighed using analytical balances (Bobkova, 2008). For numerous analytical procedures that require dry mass equivalent, a moisture conversion coefficient was calculated using the following formula:

$$K = 100 + a/100 \quad [1]$$

where *a* is the field moisture percentage. This coefficient was used to convert fresh-weight data to oven-dry equivalents for accurate quantitative comparison and standardization across samples.

Soil pH was measured in a 1:2.5 soil-to-water extract (GOST 26423-85), and carbonate content (CO_2) was assessed volumetrically (GOST 26425-85). Humus content was determined by Tyurin's titrimetric method, while particle-size distribution was analyzed via the pipette method of Kachinsky (1954) to classify sand, silt, and clay fractions. Macronutrients (available N, P, K) were extracted with distilled water and measured using spectrophotometry and flame photometry (Arinushkina, 1977; Alexandrova, 1986). Microelements (Zn, Cu, Cd, Pb) in both mobile and total forms were quantified by atomic absorption spectrometry (GOST 33850-2016). Water-soluble salts and ionic composition (HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+) were determined using titration methods (Arinushkina, 1977). All analyses were performed in triplicate. Statistical processing and data visualization (box plots, histograms, comparative tables) were conducted using IBM SPSS Statistics 28.0 software (IBM Corp., 2024).

Results and Discussion

Morphological Description of Soils

Population-1. Topar village (45.0519° N, 75.0077° E; elevation 362 m), located within the Ili River delta (Table 1). The Ili delta is one of the richest natural complexes of Zhetysu. The river splits into several branches, covering a vast area - the delta stretches approximately 120 kilometers in length and about 90 kilometers in width. This region is characterized by ridge and ridge-hilly sandy landscapes (Ministry of Environmental Protection RK, 2002). Soil type: *Weakly humus desert sandy soil.*

Hori zon	Depth (cm)	Thickness (cm)	Description
A	0-10	10	Light gray, slightly moist, loose, sandy texture, dusty structure, rich in lateral roots, weak carbonate effervescence, gra-dual transition.
B	10-35	25	Gray, dry, compacted, san-dy texture, dusty structure, presen-ce of roots, weak efferve-scence, transitional horizon.
BC	35-65	30	Pale gray-yellow, dry, stron-gly compacted, sandy texture, sparse roots, moderate carbona-te reaction.

Figure 1 and **Table 2.** *Vertical soil profile image and characteristics at sampling. Site 1, Topar Village.*

Population-2. Near Bakanas village, Balkhash district (44.91989194 N 75.982814 E; elevation 389 m). The Saryesik-Atyrau sandy region unites sand massifs located between the Ili and Karatal rivers. The main landform types in this sandy landscape include ridged, hilly, and flat sands, as well as dune sands modified by deflation processes (Budnikov, 2001).

Soil type: *Weakly humus desert sandy soil.*

Hori zon	Depth (cm)	Thickness (cm)	Description
A	0-10	10	Light gray, slightly moist, loose sandy texture, dusty structure, rich in lateral roots, medium effervescence, gradual transition.
B	10-35	25	Gray, dry, compacted, sandy and dusty structure, some main roots, weak effervescence, gradual
BC	35-65	30	Pale gray, dry, dense, sandy, with main roots, moderate carbonate effervescence.

Figure 2 and **Table 3.** *Vertical soil profile image and characteristics at sampling Site 2, Near Bakanas village.*

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Population-3. Near Miyaly village in the Balkhash district (44.50729833 N 76.74105177 E; elevation 420 m). To the west, the area borders the Ili river valley and the intrazonal meadow, meadow- swamp, and swamp soils of the Ili valley-delta region. To the east, it transitions into the intrazonal soil region of the Karatal valley-delta system, characterized by similar alluvial, floodplain, and deltaic soils (Kanaeva, 2004).

Soil type: *Weakly humus gray sandy soils*

Horizon	Depth (cm)	Thickness (cm)	Description
A	0-10	10	Light gray, moist, loose, sandy texture, dusty structure, abundant roots, weak effervescence, gradual
B_1	10-30	20	Yellowish-gray, moist, compacted, sandy-dusty, white efflorescence observed, moderate carbonate effervescence.
B_2	30-50	20	Yellow-gray, denser, with fine roots, clear dust structure, white salt streaks and moderate to strong
C	50-90	40	Pale gray, very compact, dusty-sandy texture, rootless, strong carbonate reaction.

Figure 3 and Table 4. *Vertical soil profile image and characteristics at sampling. Site 3, Near Miyaly village*

Physical properties of soils

The physical characteristics of soils in the studied *Zygophyllum fabago* L. populations reflect the arid conditions of the Ili-Balkhash region and vary across the three surveyed sites. All profiles were composed predominantly of sandy fractions, with differences in dominant particle size and moisture content. In *Population 1* (P1 - Topar), located in the Ili River delta, the soils were characterized as coarse-textured sands. The mechanical composition showed a predominance of coarse sand (34.76%) and medium sand fractions, indicating low water-holding capacity. Soil moisture ranged from 3.90% to 4.06%, which corresponds to the dry conditions of the ridged sandy plain and the limited precipitation in the area. The weakly developed sandy profile, low capillarity, and high drainage contribute to rapid desiccation of the upper horizons (Hillel, 2008).

Population 2 (P2 - Bakanas) exhibited soils with a loamy sand texture. Fine sand was the dominant particle size fraction (53.96%), followed by medium sand and silt. Moisture content was slightly higher than in P1, ranging from 4.12% to 5.60%, reflecting the wind-protected microrelief of the dune-interdune landscape. Despite the higher fine sand content, the soils remained loose and vulnerable to deflation.

In *Population 3* (P3 - Miyaly), soil physical parameters indicated improved moisture retention. The texture was also loamy sand, but with a slightly greater proportion of fine particles—fine sand accounted for 51.86%, and moisture content reached 7.16–7.64%. This population was located near the ecotone between the Ili and Karatal valleys, where shallow groundwater and occasional flooding from alluvial processes create more favorable moisture conditions (Pueppke et.al., 2018).

Overall, the physical properties of the soils in all three populations highlight the adaptive capacity of *Z.fabago* to coarse, dry, and weakly structured substrates typical of arid landscapes (Grudzinskaya, 2014). The variation in moisture and particle size distribution is closely related to microtopography and geomorphological setting, which influence plant establishment and persistence.

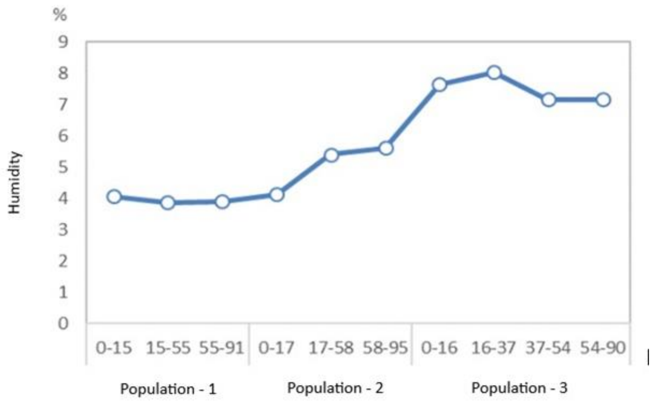

Figure 4. *Relative soil moisture index*

Granulometric composition of soils

The granulometric (particle size) composition of soils is a fundamental property that determines key physical characteristics such as porosity, water-holding capacity, infiltration, capillary rise, nutrient retention, and soil aeration and thermal regimes (Kovda, 2008). Understanding the texture and relative abundance of grain-size fractions is essential for evaluating soil fertility and plant adaptability, especially in arid and semi-arid environments (Duarte et.al., 2022).

In *Population 1* (Topar site), the soil profile was dominated by the coarse sand fraction (1.00–0.25 mm), which

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comprised 34.76% of the total particle mass. The next most abundant fraction was coarse silt (30.00%). The descending order of particle sizes was as follows: coarse sand (34.76%) > coarse silt (30.00%) > fine sand (25.00%) > clay dust (4.31%) > medium silt (3.91%) > fine silt (2.02%). According to the USDA and FAO texture classification systems, this composition qualifies as sand. Soils with such composition are typically well-drained, have low water retention, and are prone to leaching — properties that align with the arid microrelief of the Ili River delta (Sun et.al., 2022).

In *Population 2* (Bakanas site), the soil profile was dominated by the fine sand fraction (0.25–0.05 mm) at 53.96%, followed by coarse silt (28.74%). The granulometric sequence was: fine sand (53.96%) > coarse silt (28.74%) > clay dust (5.35%) > fine silt (4.68%) > coarse sand (4.46%) > medium silt (2.81%). Soil of this populations is classified as loamy sand. Such soils retain slightly more moisture than pure sands and exhibit moderate nutrient-holding capacity (Ceballos et.al., 2002). The dune-interdune landscape of Saryesik-Atyrau desert contributes to the relative fineness and better structural development of these soils.

In *Population 3* (Miyaly site), the granulometric profile was similar to P2. The fine sand fraction was dominant at 51.86%, followed by coarse silt (30.92%) (Figure 5). The distribution sequence was: fine sand (51.86%) > coarse silt (30.92%) > clay dust (5.12%) > fine silt (4.32%) > coarse sand (4.16%) > medium silt (3.62%). This profile also corresponds to loamy sand. The slightly higher presence of silt and clay components indicates improved moisture-holding capacity and root penetration potential (Wankmüller et.al., 2024), particularly relevant in the ecotonal floodplain setting between the Ili and Karatal rivers.

In all three populations, sand and silt fractions predominated, with minimal clay content. This textural structure is typical for arid and semi-arid alluvial plains and desert margins (Wang et.al., 2020). Despite low nutrient retention potential, such soils can support halophytic and xerophytic species like *Z.fabago*, especially when shallow groundwater is present or periodic flooding occurs.

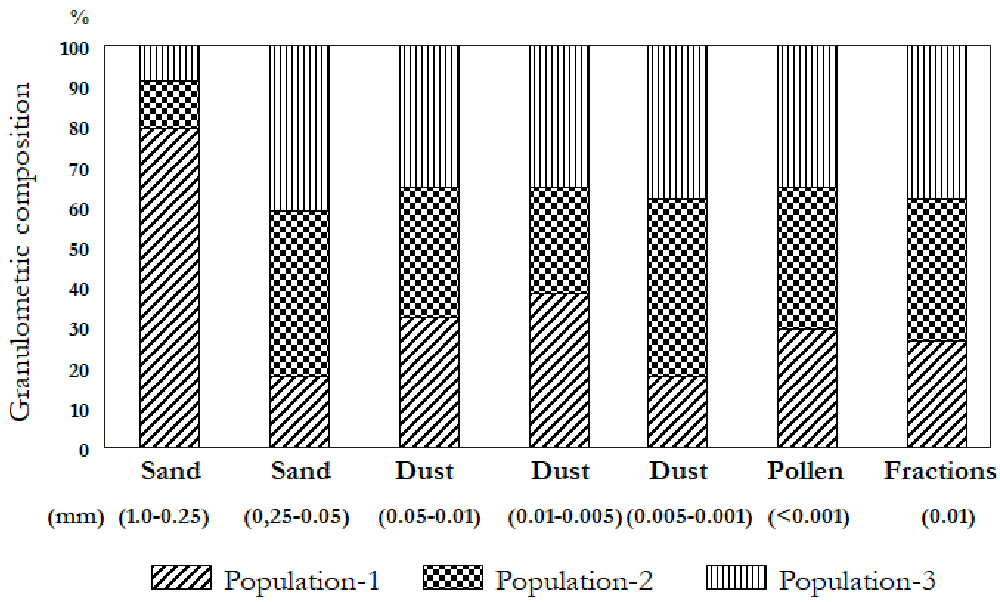

Figure 5
Granulometric composition of soils

Chemical properties of soils

The chemical analysis of soils from the three *Zygophyllum fabago* L. populations revealed that the studied sites are characterized by low humus content, high alkalinity, and variable carbonate accumulation.

In Population 1, the humus content in the 0–91 cm soil profile was very low, ranging from 0.24% to 0.42%, with a clear decrease in humus content with increasing depth (*Figure 6*). Soil pH varied from 8.41 to 8.89, indicating a medium to strongly alkaline reaction (USDA NRCS, 1998). The carbonate content (CO_2) ranged from 0.58% to 1.49%, with higher concentrations in the upper horizons, gradually decreasing with depth. These values suggest low biological activity

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and weak profile differentiation (Waksman, 1937).

In Population 2, the humus content ranged from 0.60% to 0.87% in the 0–95 cm profile. The pH values were between 8.44 and 8.52, indicating a medium alkaline environment. CO_2 content ranged from 0.68% to 1.52%, with higher values in surface horizons, similar to P1 (*Figure 6*). Despite being slightly more developed in structure, the profile remained weakly humified.

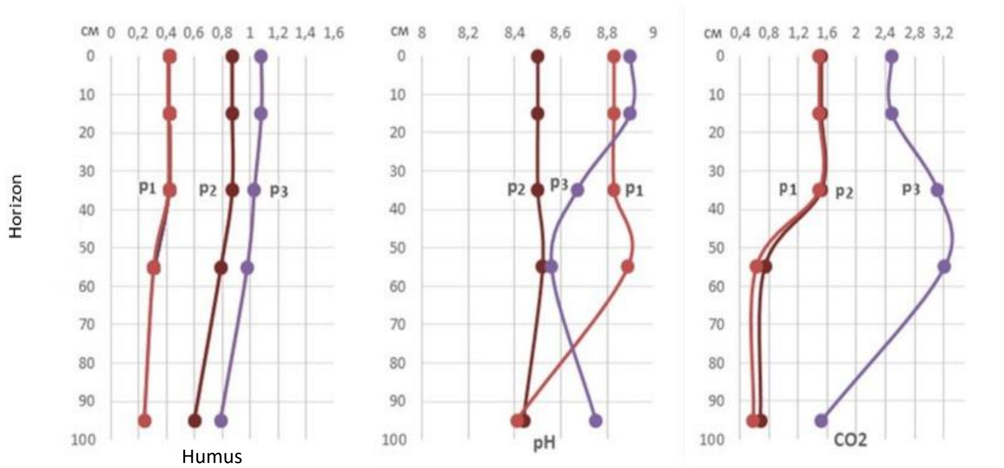

Figure 6
Humus, CO_2 and pH indicators in the soil, %

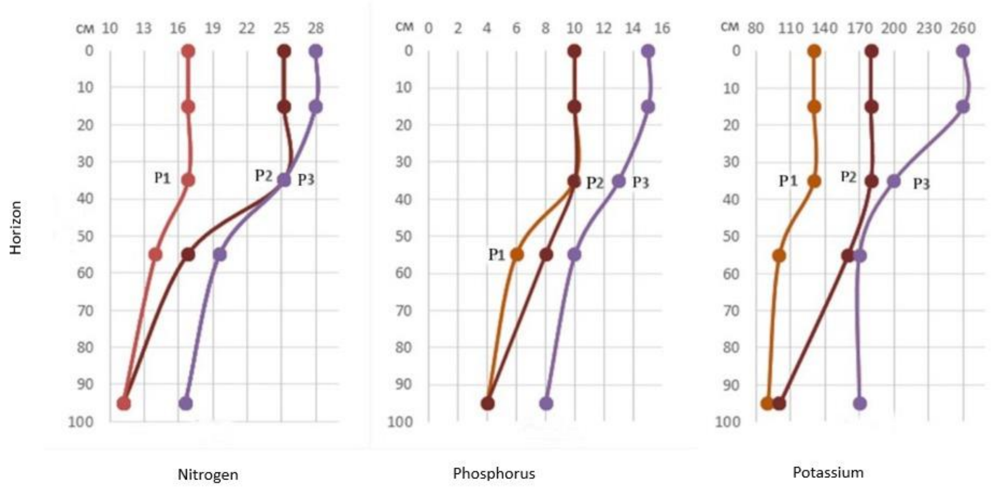

Figure 7
Indicators of mobile nitrogen, phosphorus, potassium in the soil, mg/kg

In Population 3, humus content was relatively higher, ranging from 0.79% to 1.08% within the 0–90 cm profile. Soil pH values ranged from 8.56 to 8.90, also indicating moderate to strong alkalinity (USDA NRCS, 1998). CO_2 content was significantly higher, between 1.52% and 3.21%, showing evidence of stronger carbonate accumulation. Among the three populations, P3 had the highest humus levels, likely due to better moisture retention and partial alluvial influence (*Figure 4*) (Waksman, 1937).

As for available macronutrients, soils of P1 contained 11.2–16.8 mg/kg of nitrogen, 4–10 mg/kg of phosphorus, and 90–130 mg/kg of potassium. All values were rated as low or very low. Soils of P2 had slightly higher contents: 11.2–25.2 mg/kg N, 4–10 mg/kg P, and 100–180 mg/kg K, though still within the low fertility category. In P3, nitrogen ranged from 16.6–28.0 mg/kg, phosphorus from 8–15 mg/kg, and potassium from 170–260 mg/kg. Although nitrogen and phosphorus remained low, potassium levels were notably higher in P3. Among macronutrients, potassium was the most abundant, particularly in P3, while nitrogen and phosphorus were limiting across all sites (Figure 6) (Kamensky, 2000). Nitrogen (N), phosphorus (P), and potassium (K) are primary plant nutrients, and their availability provides key information about soil fertility (Roy, 2006). Their low concentrations in the studied soils explain the overall poor nutrient status of the habitats, confirming the ecological adaptability of *Z. fabago* to nutrient-deficient environments. The mobile forms of micronutrients were also analyzed. In P1, zinc (Zn) ranged from 0.0–1.30 mg/kg, copper

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(Cu) from 0.80–1.00 mg/kg, cadmium (Cd) from 0.20–0.60 mg/kg, and lead (Pb) from 0.10–0.50 mg/kg. In P2, Zn ranged from 0.90–1.10 mg/kg, Cu from 0.70–1.00 mg/kg, Cd from 0.60–0.70 mg/kg, and Pb from 0–0.60 mg/kg. P3 soils had Zn 1.00–1.30 mg/kg, Cu 0.90–1.60 mg/kg, Cd 0.60–1.10 mg/kg, and Pb 0–0.60 mg/kg (Table 5). None of the mobile forms of these elements exceeded the maximum permissible concentrations (MPC) (Kamensky, 2000). The total forms of micronutrients were also determined. In P1, total Zn was 24.40–32.80 mg/kg, Cu 5.60–8.40 mg/kg, Cd) 1.20–5.20 mg/kg, and Pb 5.60–8.40 mg/kg. In P2, Zn ranged 42.00–63.20 mg/kg, Cu 16.40–17.60 mg/kg, Cd 6.80–10.40 mg/kg, Pb 4.40–8.00 mg/kg. In P3, Zn was 41.20–67.60 mg/kg, Cu 11.20–22.40 mg/kg, Cd 1.20–2.80 mg/kg, and Pb 3.20–5.20 mg/kg. While Zn, Cu, and Pb concentrations did not exceed MPC in any population, total cadmium levels in P2 and P3 exceeded the threshold by more than twofold, indicating potential environmental concern (Table 5) (Kamensky, 2000).

Table 5
Mobile and total forms of microelements in soil, mg/kg

	Mobile microelements				Total microelements			
	Population 1							
Sampling depth, cm	**Zn**	**Cu**	**Cd**	**Pb**	**Zn**	**Cu**	**Cd**	**Pb**
0-15	0,8	0,9	0,6	0,2	24,4	5,6	1,2	8,4
15-55	1,3	1	0,6	0,5	32,4	7,6	2	6,4
55-91	1,1	0,8	0,2	0,1	32,8	8,4	5,2	5,6
	Population 2							
0-17	0,9	1	0,6	0,4	42	17,6	6,8	8
17-58	1,1	0,9	0,6	0,2	63,2	16,4	10,4	6,4
58-95	1,1	0,7	0,7	0,6	44,4	16,4	8,8	4,4
	Population 3							
0-16	1,2	0,9	0,6	0	67,6	14,8	1,2	5,2
16-37	1,1	1,6	0,9	0,6	53,6	22,4	2	3,2
37-54	1,3	1,2	1,1	0,2	56,8	22	2	4,8
54-90	1	1,1	0,8	0,3	41,2	11,2	2,8	4,4

Salinization is one of the primary degradation processes determining the ecological condition of soils, particularly in arid and semi-arid regions of Central Asia (Khasanov et al., 2023). In such landscapes, where evapotranspiration significantly exceeds precipitation, soluble salts tend to accumulate in the soil profile, impairing soil structure, reducing fertility, and limiting vegetation growth (Glazovskaya, 2012). Soils from Population 3 (Miyaly) exhibited the highest salinity levels. The upper horizons of this profile were classified as moderately saline, while the deeper layers were slightly saline (Stavi et.al., 2021). These features may be attributed to its proximity to the Karatal valley alluvial plain and the presence of shallow saline groundwater, which contributes to capillary rise and surface accumulation of salts during dry seasons. In contrast, the soils of Population 1 (Topar) and Population 2 (Bakanas) were classified as non-saline, with total soluble salt content remaining below ecological thresholds for salinity stress. The presence of coarse sandy textures in P1 and well-drained dune environments in P2 likely contribute to salt leaching and prevent surface accumulation (Table 6).

The main anions identified across all samples were HCO_3^-, Cl^-, and SO_4^{2-}, while the dominant cations included Ca^{2+}, Mg^{2+}, and Na^+. Although only one of the three populations (P3) exhibited moderate salinization in surface horizons, this is ecologically significant. Even low to moderate salinity levels can impact root development, water uptake, and nutrient availability, especially in species with limited salt tolerance (Munns et.al., 2008). However, the persistence of *Z.fabago* in such conditions demonstrates its adaptation to harsh, saline-prone environments.

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Table 6. *Water extract from absolutely dry soil*

Sample	Depth	Salt content	Total HCO_3^-	Total HCO_3^-	CO_3^{2-}	CO_3^{2-}	Cl^-	Cl^-	SO_4^{2-}	SO_4^{2-}
	cm	%	%	mg/eq	%	mg/eq	%	mg/eq	%	mg/eq
P-1	0-15	0,086	0,039	0,64	0,001	0,04	0,003	0,07	0,021	0,44
P-1	15-55	0,061	0,041	0,68	0,001	0,04	0,003	0,07	0,001	0,01
P-1	55-91	0,110	0,051	0,84	0,001	0,04	0,003	0,07	0,026	0,55
P-2	0-17	0,069	0,039	0,64	0	0	0,004	0,11	0,009	0,19
P-2	17-58	0,087	0,046	0,76	0	0	0,004	0,11	0,016	0,33
P-2	58-95	0,068	0,041	0,68	0,001	0,04	0,001	0,04	0,007	0,15
P-3	0-16	0,330	0,029	0,48	0	0	0,005	0,15	0,201	4,18
P-3	16-37	0,063	0,037	0,6	0,001	0,04	0,003	0,07	0,008	0,17
P-3	37-54	0,078	0,039	0,64	0	0	0,004	0,11	0,017	0,35
P-3	54-90	0,102	0,044	0,72	0,001	0,04	0,003	0,07	0,028	0,58

Sample	Depth	Ca^{2+}	Ca^{2+}	Mg^{2+}	Mg^{2+}	Na^+	Mg^{2+}	K^+	K^+
	cm	%	mg/eq	%	mg/eq	%	mg/eq	%	mg/eq
P-1	0-15	0,01	0,5	0,004	0,3	0,006	0,27	0,003	0,09
P-1	15-55	0,008	0,4	0,002	0,2	0,002	0,07	0,004	0,1
P-1	55-91	0,01	0,5	0,006	0,49	0,007	0,28	0,007	0,18
P-2	0-17	0,004	0,2	0,006	0,49	0,004	0,18	0,003	0,07
P-2	17-58	0,01	0,5	0,006	0,49	0,004	0,18	0,001	0,03
P-2	58-95	0,01	0,5	0,002	0,2	0,002	0,07	0,004	0,1
P-3	0-16	0,082	4,1	0,006	0,49	0,002	0,11	0,004	0,11
P-3	16-37	0,01	0,5	0,002	0,2	0,003	0,14	0	0
P-3	37-54	0,01	0,5	0,006	0,49	0,002	0,11	0	0
P-3	54-90	0,01	0,5	0,006	0,49	0,005	0,23	0,006	0,15

Conclusions

This study presents a detailed assessment of the morphological, physical, and chemical properties of soils across three natural populations of *Zygophyllum fabago* L. in the Ile-Balkhash region of Kazakhstan. The findings confirm that the species thrives in weakly humus-rich sandy and loamy sand soils with alkaline pH and low nutrient content. While all populations exhibited coarse-textured, well-drained profiles typical of arid and semi-arid landscapes, notable differences were observed in moisture retention, salinity levels, and microelement accumulation. Soils in Population 3 (Miyaly) showed moderate salinization and higher potassium levels, highlighting the influence of geomorphological and hydrological factors such as shallow groundwater and floodplain settings. Despite nutrient limitations and occasional salinity stress, *Z.fabago* demonstrates a remarkable adaptability, making it a valuable indicator species for soil quality and a potential candidate for ecological restoration in salt-affected environments. These results highlight a baseline for further research on halophytic plant-soil interactions and support the development of sustainable land management strategies in the arid ecosystems of Central Asia.

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