EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 72 (2026): 15-27
Journal homepage: https://eqa.unibo.it/

published by

Soil morphological, chemical and salinity characteristics of *Capparis herbacea* Willd. populations in Southern Kazakhstan

Orynbassar Tleuberlina[1], Almira Daulbayeva[1], Kaliash Stamkulova[1], Akerke Kenesbay[2], Gulbarshyn Satbaeva[1], Assem Mamurova[3], Aigul Yedilova[3,4], Gulzat Kairanova [3,4*], Zhaukhar Kenzhebayeva[3], Asselkhan Otegenova[4], Ainur Mukash[4] , Aidana Toregeldiyeva[4], Gulnafis Demzhanova[4], Nurzhigit Urnesh[4], Amina Kairanova[5]

[1] NARXOZ University, Almaty, Kazakhstan
[2] Plant World Cadaster Laboratory, Institute of Botany and Phytointroduction Almaty, Kazakhstan;
[3] Department of Botany and Agroecology, Faculty Biology and Biotechnology, al-Farabi Kazakh National University, Almaty, Kazakhstan
[4] Department of Fundamental Medicine, Faculty of Medicine and Healthcare, al-Farabi Kazakh National University, Almaty, Kazakhstan
[5] Nazarbayev University Astana, Kazakhstan

* Corresponding author E.mail: gulzatkajranova@gmail.com

Article info
Received 29/9/2025; received in revised form 10/12/2025; accepted 10/1/2026
DOI: 10.60923/issn.2281-4485/22936

Abstract
This study provides the first integrated characterization of soils associated with natural populations of *Capparis herbacea* Willd. in southern Kazakhstan. Field surveys and soil sampling were conducted in June-July 2023 across three contrasting sites: (Population 1, Sogeti Gorge), piedmont plain (Population 2, Merki), and semi-arid lowland (Population 3, Saryagash) environments. Standard profile descriptions and laboratory analyses followed national GOST and classical pedological methods. Across sites, soils were alkaline (pH 7.8-8.9) and carbonate-rich, with low humus (0.18-6.3%). Texture ranged from light loam (P1) to medium loam (P2) and sandy loam (P3); moisture distribution varied from higher values in mountain soils (up to 21.6%) to more uneven patterns in semi-arid lowlands (6.5-20.7%). Available macronutrients were generally limited: P2 showed near-absent phosphorus, while P3 had relatively higher potassium. Salinity contrasted sharply: P1-P2 non-saline (total salts ~0.037-0.062%), whereas P3 exhibited moderate to strong salinity (0.082-0.910%), with upper horizons moderately saline and deeper horizons strongly saline, dominated by sulfates and calcium ions. These findings represent the first baseline data on soils supporting *Capparis herbacea* Willd. in southern Kazakhstan. *Capparis herbacea* Willd. demonstrates strong ecological plasticity, tolerating both carbonate non-saline and sulfate-enriched saline soils. Its adaptability highlights potential for use as a soil quality indicator and in restoration of degraded lands in Central Asia

Keywords: *Capparis herbacea, soil morphology, granulometric composition, soil salinity, Southern Kazakhstan.*

Introduction

Soil degradation is a major environmental challenge in arid and semi-arid regions of Central Asia, manifesting through erosion, salinization, desertification, and decline in fertility (Dou et al., 2022). In Kazakhstan, particularly in the southern and southeastern regions, extreme climate and intensive land use aggravate soil vulnerability (Mamurova et.al., 2025b), undermining both ecosystem stability and agricultural productivity (Jiang et al., 2022; Juliev et al., 2023). Halophytic and xerophytic plants play a key role in stabilizing fragile soils, maintaining ecological balance, and serving as bioindicators of environmental change (Flowers and Colmer, 2008; Munns and Tester, 2008). The genus *Capparis* is notable for its tolerance to alkaline, saline, or nutrient-poor soils (Zhang and Ma,

DOI: 10.60923/issn.2281-4485/22936

2018) The species retains biochemical and physiological traits that allow survival in harsh edaphic conditions (Wang et al., 2022). Though direct studies on *C.herbacea* are limited (Fig. 1), recent phytochemical analysis revealed that its root extracts (chloroform, methanol) exhibit strong antioxidant activity, and the main volatile compounds include T-cadinol, m-cymene, pulegone, and σ-amorphene (Tleuberlina et al., 2023a). In Central Asia, the species has also been noted in ethnobotanical practices, where its extracts are tradizionally employed to alleviate digestive and inflammatory disorders (Tleuberlina et al., 2023b). This underscores *C.herbacea* as a promising source of bioactive metabolites. Moreover, some *Capparis* spp. are used in erosion control and landscape restoration under arid conditions (Wang and Zhang, 2022). Despite its ecological importance, information on the soil environment of *Capparis herbacea* populations in Kazakhstan remains scarce. This gap limits our knowledge of the edaphic factors that support its survival in arid and semi-arid conditions (Mamurova et.al., 2025c). This study is the first to investigate soils associated with three natural populations of *C.herbacea* in southern Kazakhstan *(Fig. 2).* The research integrates morphological characterization, granulometric analysis, humus content, soil moisture, nutrient availability (N, P, K), salinity, carbonate accumulation, and pH variability. By establishing baseline data, it advances the under-standing of halophyte-soil interactions and provides applied knowledge for land degradation mitigation, restoration of salinized and eroded soils, and sustainable use of marginal lands in Central Asia.

Figure 1. *Capparis herbacea Willd. in its natural habitat (southern Kazakhstan)*

Materials and Methods

Research area (Fig. 2) and taxonomic identification

The taxonomic identity of *Capparis herbacea* Willd. (Fig. 1) was verified by a specialist from the Institute of Botany and Phytointroduction (Almaty, Kazakhstan) using the Flora of Kazakhstan (1956-1966) and the Illustrated Plant Identification Guide of Kazakhstan (1969). Following the taxonomic verification, soil sampling was carried out in the natural habitats of the species.

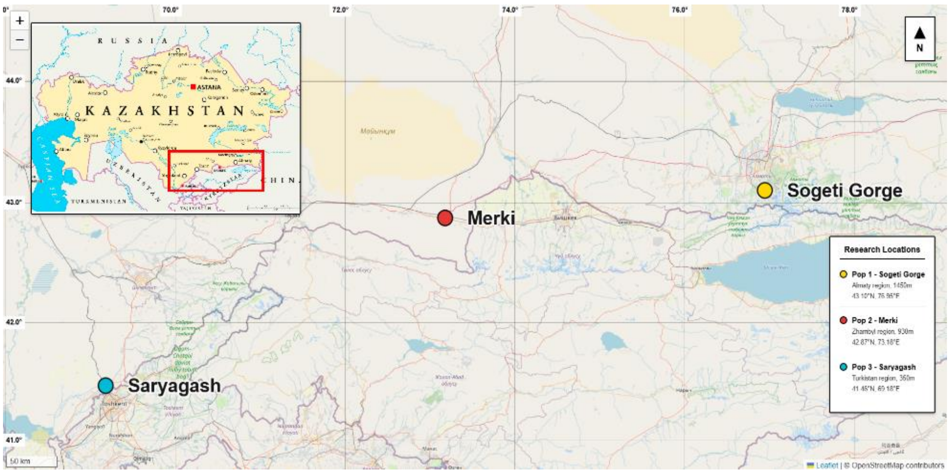


Figure 2 *Location of the three studied populations of Capparis herbacea Willd. in southern Kazakhstan (Population 1 - Sogeti Gorge, Almaty region; Population 2 - Merki, Zhambyl region; Population 3 - Saryagash, Turkistan region)*

№	Location	Altitude, m asl	Geographical coordinates
Population 1	Sogeti Gorge, Ile Alatau (Almaty region)	1450	42°47.395' N, 73°02.509' E
Population 2	Merki, Kyrgyz Alatau (Zhambyl region)	930	41°21.556' N, 68°56.447' E
Population 3	Saryagash, Turkistan region	350	41°21.556' N, 68°56.447' E

DOI: 10.60923/issn.2281-4485/22936

Relief

The habitats of *Capparis herbacea* in southern Kazakhstan span contrasting geomorphological zones, including mountain slopes, piedmont areas, and semi-arid plains (Hu et.al., 2020). In the Ile Alatau region, steep slopes and colluvial deposits dominate, with active erosion and sediment transport shaping shallow and skeletal soils frequently subject to mudflows (Mussina et al., 2023). The piedmont zones transition into gently sloping alluvial and proluvial terrains, promoting sediment deposition and soil accumulation processes (Musina et.al., 2025). In the Turkistan lowlands, aeolian activity prevails, forming dune systems, salt flats (sors) - features common in Central Asian deserts (Mustafayev et al., 2023). These relief patterns influence hydrological flow, sediment redistribution, and soil genesis, thereby creating distinct edaphic gradients in moisture, texture, carbonate, and salinity (Liu et.al., 2022) that affect *C.herbacea* distribution and adaptation.

Climatic Conditions

The natural habitats of *Capparis herbacea* in Southern Kazakhstan are characterized by a sharply continental and predominantly arid climate, with pronounced seasonal and diurnal fluctuations in temperature and moisture availability (Kakabayeva et.al., 2024). Winters are cold, with minimum air temperatures often dropping below -25 °C, whereas summers are hot and dry, with maxima reaching 38-40 °C (Adenova et.al., 2024). Annual precipitation is unevenly distributed, averaging 250-400 mm in the piedmont and semi-arid plains and up to 600-700 mm in mountain foothills, much of it falling in spring and early summer (Zhang et al., 2020). Evaporation rates frequently exceed 900-1000 mm per year, resulting in significant moisture deficits that enhance aridity and favor the development of xerophytic and halophytic vegetation, including *C.herbacea* (Aralova et al., 2018). Periodic droughts and high solar radiation intensify evapotranspiration and accelerate soil salinization processes, particularly in the semi-arid lowlands of Turkistan region (Tleuova et.al., 2023). These climatic constraints strongly regulate soil moisture dynamics, nutrient availability, and carbonate accumulation, thereby shaping the ecological niches where *C.herbacea* persists and adapts.

Field survey and laboratory methods

Field surveys were conducted from June to July 2023 across three populations of *Capparis herbacea* in the southern Kazakhstan. At each site, representative soil profiles were excavated to depths of 90-95 cm using the key transect method (Mamurova et.al., 2025a). Morphological descriptions included horizon depth, color, structure, compaction, carbonate effervescence, and root density, following standardized field protocols (Rozanov, 2004; Korolyuk, 2012).Soil sampling was complemented by laboratory analyses carried out at the Kazakh Research Institute of Soil Science and Agro-chemistry named after U.U.Uspanov (Almaty, Kazakh-stan). 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 weig-hed, ovendried at 105 °C for 5 hours, cooled in a desiccator (VENTI-CELL, Germany), and reweighed using analytical balances (MBS-300N, Germany) (Bobkova, 2008). For numerous analytical procedures that require dry mass equivalent, a moisture conversion coefficient was cal-culated using the following formula:

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

where *a* is the field moisture percentage. This coeffi-cient was used to convert fresh-weight data to oven-dry equivalents for accurate quantitative compa-rison and standardization across samples. Soil pH was measured potentiometrically in a 1:2.5 soil-to-water suspension (GOST 26423-85), while carbon-ate content (CO_2) was determined volumetrically by acid neutralization (GOST 26425-85). Organic matter was quantified as humus content using Tyurin's titrimetric method (GOST 23740-79). Particle-size distribution was deter-mined by the Kachinsky pipette method (GOST 125-36-2014), which confirmed that populations 1 and 2 were classified as medium loam, whereas population 3 belonged to the light loam category. Macronutrients (N, P, K) were extracted with distilled water and quan-tified by spectrophotometry for phosphorus, flame photometry for potassium, and titration for nitrogen (Arinushkina, 1977; Alexandrova, 1986; GOST 26205-91). Exchangeable bases and water-soluble salts (HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}; Ca^{2+}, Mg^{2+}, Na^+, K^+) were determined by titrimetric methods (GOST 26425-85).

Statistical analysis

Standard methods for calculating averages and their average errors were used for mathematical processing of the results. The data was processed using the IBM SPSS Statistics 28.0 (IBM Corp., 2024). All results are presented as mean values accompanied by their standard deviations (SD).

DOI: 10.60923/issn.2281-4485/22936

Results and Discussion

Morphological Description of Soils

Population-1. Sogeti Gorge (42°47' N, 73°02' E; elevation-1450 m), located on the northern slopes of the Ile Alatau range in the Almaty region. The Gorge represents a typical mountain landscape of the northern Tien Shan, with steep slopes, narrow valleys and rocky outcrops shaped by Paleozoic formations. The geomorphology is dominated by denudation and colluvial processes, resulting in the accumulation of coarse rock fragments and shallow soil cover (Nassyrov et.al., 2020). Based on the morphological characteristics of the Sogeti Gorge soil profile, including a shallow A_1-B-BC horizon sequence, light to medium loam texture, the presence of skeletal material derived from colluvial-deluvial deposits, weak to strong carbonate effervescence increasing with depth, and the absence of salinity, the soil corresponds to a Calcaric Cambisol (Loamic, Skeletic) according to the World Reference Base for Soil Resources (WRB, 2022). Under the USDA Soil Taxonomy (Soil Taxonomy, 2022), the profile is classified as a Typic Haplocambid, which is typical for weakly developed mountain soils formed under semi-arid to sub-humid conditions with active denudation processes. This classification fully reflects the observed field properties of the mountain grey-brown soils in the Sogeti Gorge and aligns with their genesis on steep, erosion-prone slopes of the Ile Alatau range.

Soil type: Mountain grey-brown soil.

Horizon	Depth (cm)	Thickness (cm)	Description
A_1	0-10	10	Dark brown with greyish shade, slightly compacted, loose, rich in plant roots; dry flakes present; granular structure; light loam texture; weak carbonate effervescence; clear boundary with next horizon.
B	10-30	20	Light brown with yellowish shade; blocky-prismatic structure; compacted; light loam texture; flaky inclusions observed; weak carbonate effervescence; gradual transition.
BC	30-70	40	Grey-brown; dense, blocky with flaky features; medium loam texture; plant root residues and carbonate inclusions present; strong carbonate effervescence.

Population-2. Merki (42°51' N, 73°56' E; elevation - 930 m), located in the piedmont plains of the Kyrgyz Alatau, Zhambyl region. The landscape is characterized by gently sloping alluvial-proluvial deposits, where sediment accumulation and moderate erosion processes shape the soil cover. This geomorphological setting supports relatively deeper and more developed soils compared to the mountain zone (Aldazhanova et al., 2022). The piedmont soil of Population 2 (Merki) is formed on alluvial-proluvial deposits and is characterized by an A_1-B-BC horizon sequence, medium loam texture, strongly alkaline reaction (pH 8.76-8.96), very low humus content (0.18-1.92%) (*Figure 5*), and a pronounced increase in carbonate content with depth, including visible carbonate films and strong effervescence in the BC horizon. According to the World Reference Base for Soil Resources (WRB, 2022), these properties correspond to a Calcaric Haplic Cambisol (Loamic), reflecting a carbonate-rich loamy soil with a typical cambic horizon and moderate profile development (WRB, 2022). Under the USDA Soil Taxonomy, the same profile is consistent with a Typic Haplocalcid, an arid-region soil with a carbonate-enriched subsoil and high base saturation within the upper meter of the profile, which matches its strongly alkaline, carbonate-rich nature on the Kyrgyz Alatau piedmont plain (Soil Taxonomy, 2022).

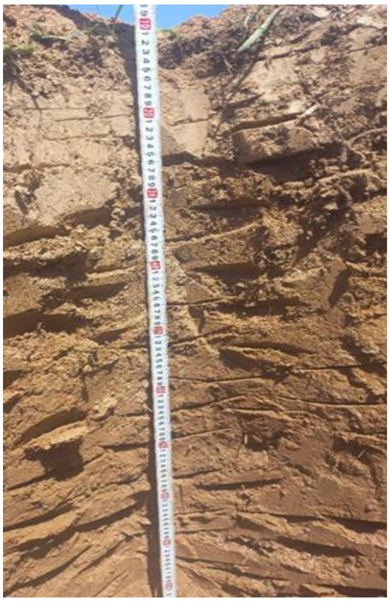
DOI: 10.60923/issn.2281-4485/22936

Soil type: Light chestnut (foothill alluvial-proluvial).

Horizon	Depth (cm)	Thickness (cm)	Description
A_1	0-12	12	Brown with light grey shade; slightly compacted, loose; rich in plant roots; granular structure; light loam texture; weak carbonate effervescence; distinct boundary with underlying horizon.
B	12-32	20	Light brown; blocky-prismatic structure; compacted; medium loam texture; occasional flaky inclusions; weak carbonate effervescence; gradual transition.
BC	32-70	38	Brownish-grey; dense, blocky; medium loam texture; carbonate films and root residues present; strong carbonate effervescence.

Population-3. Saryagash (41°21' N, 68°56' E; elevation 350 m), located in the semi-arid plains of the Turkistan region. The area is dominated by aeolian landscapes with sandy ridges, stabilized dunes, and saline depressions. Geomorphological processes include wind-driven redistribution of sediments and salt accumulation in closed depressions, creating conditions for soil salinization (Liu et.al., 2020). The soil profile of Population 3 (Saryagash) is developed on semi-arid lowland sediments and is characterized by a weakly differentiated A_1-AB-B-C horizon sequence. The upper horizons (A_1, AB, B; 0-70 cm) are light grey to pale yellowish, granular-dusty to dusty-blocky, with sandy loam texture and moderate to strong carbonate effervescence, while the C horizon (70-95 cm) is pale yellowish, prismatic, clay-loam, and contains visible carbonate accumulations with moderate effervescence. According to the World Reference Base for Soil Resources, these features indicate a weakly developed, carbonate-rich loamy soil with a calcic subsoil formed under arid to semi-arid conditions, which is consistent with classification as a Haplic Calcisol (Loamic) (IUSS Working Group WRB, 2022). Under the USDA Soil Taxonomy, the combination of an arid climatic setting, carbonate-enriched subsurface horizons and high base saturation within the upper meter of the profile corresponds to a Typic Haplocalcid, while the elevated sulfate salinity reflects additional salinity stress typical for semi-arid lowland plains (USDA Soil Taxonomy,2022).

Soil type: Southern light-grey.



Horizon	Depth (cm)	Thickness (cm)	Description
A_1	0-10	10	Light grey; granular-dusty; moderately compacted; root-rich; dry flakes present; sandy loam; moderate effervescence; gradual transition.
AB	10-30	20	Pale brown; dusty-granular; loose; sandy loam; roots present; strong effervescence; clear boundary.
B	30-70	40	Pale yellowish; dusty-blocky; very loose; sandy loam; occasional roots; strong effervescence; gradual transition.
C	70-95	25	Pale yellowish; prismatic; compacted; clay-loam; carbonate accumulations; moderate effervescence.

DOI: 10.60923/issn.2281-4485/22936

Physical properties of soils

The physical properties of soils supporting *Capparis herbacea* populations in southern Kazakhstan reflect the contrasting geomorphological and climatic conditions of mountain, piedmont, and semi-arid landscapes (Fig. 3). Across all three populations, soils were composed predominantly of loamy fractions, with differences in texture and moisture dynamics corresponding to relief and sediment origin (Yedilova et.al., 2025).

In Population 1 (P1 - Sogeti Gorge, Ile Alatau), soils were classified as light loam, developed on colluvial-deluvial material. The profile showed relatively high surface moisture (21.55 %) that declined with depth to 9.32 %, indicating rapid infiltration and limited water-holding capacity in stony mountain soils. The light loam texture, weak aggregation, and shallow rooting depth reduce capillary rise, resulting in uneven moisture distribution (Li et al., 2024). These features are typical of mountain grey-brown soils subjected to steep slope processes and intensive drainage (Dai and Cheng, 2022).

In Population 2 (P2 - Merki, Kyrgyz Alatau), soils were characterized as medium loam formed on alluvial-proluvial deposits. Moisture distribution was relatively uniform, ranging from 14.32 % to 15.87 % across horizons. The balanced texture and moderate compacttion promote better water retention than in P1, while carbonate accumulations at depth indicate leaching and redeposition processes (Egli et.al., 2001). These piedmont soils, with their stable structure and higher moisture reserves, represent more favorable edaphic conditions for plant establishment compared to mountain sites (Duniway et al., 2018).

In Population 3 (P3 - Saryagash, Turkistan region), soils exhibited sandy loam to light loam textures, reflecting aeolian and alluvial sedimentation. Moisture values were highly variable: from as low as 6.50 % in the surface horizon to 20.66 % in deeper layers. Such contrasts reflect both high evaporative loss at the surface and moisture accumulation at depth due to capillary rise and shallow groundwater influence (Zhao et al., 2023). The presence of carbonate concretions and higher effervescence in subsoil horizons further confirm processes of secondary salinization, typical for semi-arid plains with limited precipitation and strong evaporative demand (Gnann et al., 2025).

Overall, the physical properties of soils in the three populations highlight the ecological amplitude of *C.herbacea*. Mountain soils are shallow, stony, and drought-prone; piedmont soils are loamy with stable moisture reserves; and semi-arid lowland soils exhibit strong moisture and salinity gradients. These differences illustrate how relief and parent material shape soil–water relations, thereby influencing the survival strategies and adaptive capacity of *C.herbacea* under arid and semi-arid conditions (Gnann et al., 2025).

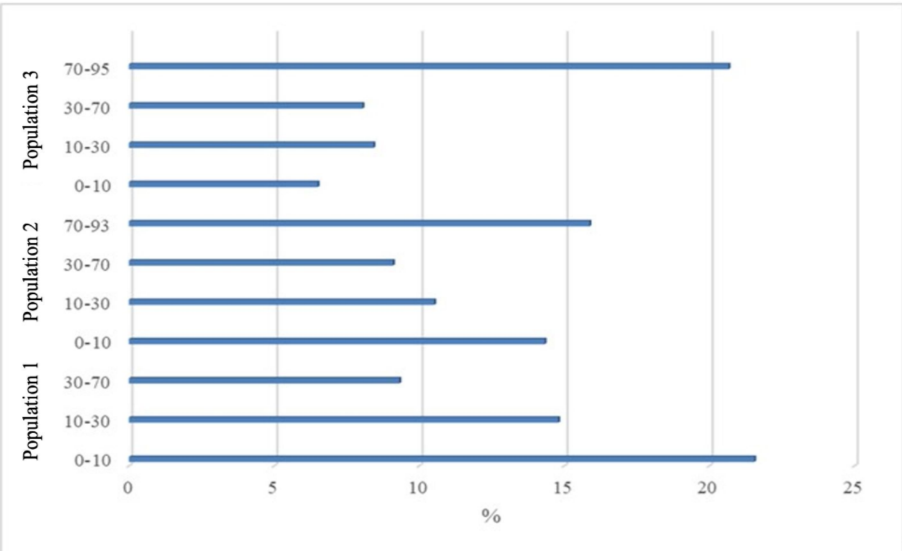


Figure 3
Relative soil moisture index

Granulometric composition of soils

The granulometric composition of soils in the studied *Capparis herbacea* populations demonstrates clear textural differences associated with geomorphological settings and sedimentary origin (Fig. 4).

In Population 1 (Sogeti Gorge, Ile Alatau), coarse silt (0.05-0.01 mm) was the dominant fraction, accounting for 35.85% of the soil mass, followed by fine sand (24.06%) and fine silt (18.62%). Clay and dust fractions were present in smaller amounts (12.38% and 7.38%),

DOI: 10.60923/issn.2281-4485/22936

while coarse sand contributed only 1.68%. This distribution reflects the colluvial-deluvial nature of mountain grey-brown soils, where slope processes supply both silt and sand fractions (Zádorová and Penížek, 2018) and where silty mantles in high-mountain settings often have an aeolian contribution (Yang et al., 2016); such textural make-ups enhance aeration but limit water-holding capacity relative to finer-textured soils (Saxton and Rawls, 2006).

In Population 2 (Merki, Kyrgyz Alatau), fine sand (0.25-0.05 mm) dominated the granulometric profile, representing 47.53% of the total mass. Other important fractions included fine silt (15.61%) and coarse silt (15.52%), followed by dust (11.51%) and medium silt (8.21%). Coarse sand contributed minimally (1.60%). The prevalence of fine sand and silty particles corresponds to alluvial-proluvial sedimentation on piedmont plains in the Tien Shan foreland (Lu et al., 2010), and loamy textures in such settings typically afford moderate moisture retention compared to sandier matrices (Świtoniak et al., 2022).

In Population 3 (Saryagash, Turkistan region), soils were dominated by fine sand (51.30%) and coarse silt (19.02%). Additional fractions included fine silt (12.37%), medium silt (10.74%), dust (3.88%), and coarse sand (2.25%). This structure indicates sandy loam to light loam texture shaped by aeolian and alluvial processes (Ravi et al., 2011). The dominance of fine sand enhances porosity and drainage, while silt fractions modestly increase retention but, within a sandy matrix, overall water storage remains limited (Wankmüller et al., 2024). In semi-arid lowlands, such textures are often associated with strong evaporative demand and, where groundwater is shallow, with secondary salinization patterns (Aboelsoud et al., 2023; Jiang et al., 2022). Overall, soils of Populations 1 and 2 are classified as medium loam, while Population 3 corresponds to light loam. The differences in granulometric composition are linked to ecological conditions: mountain soils balance coarse and fine particles under erosion-accumulation regimes (Zádorová et al., 2023), piedmont soils exhibit loamy textures favorable for plant establishment and moderate moisture retention, while semi-arid lowland soils are sandy and loose, prone to desiccation and, under suitable hydrological conditions, to secondary salinization (Aboelsoud et al., 2023).

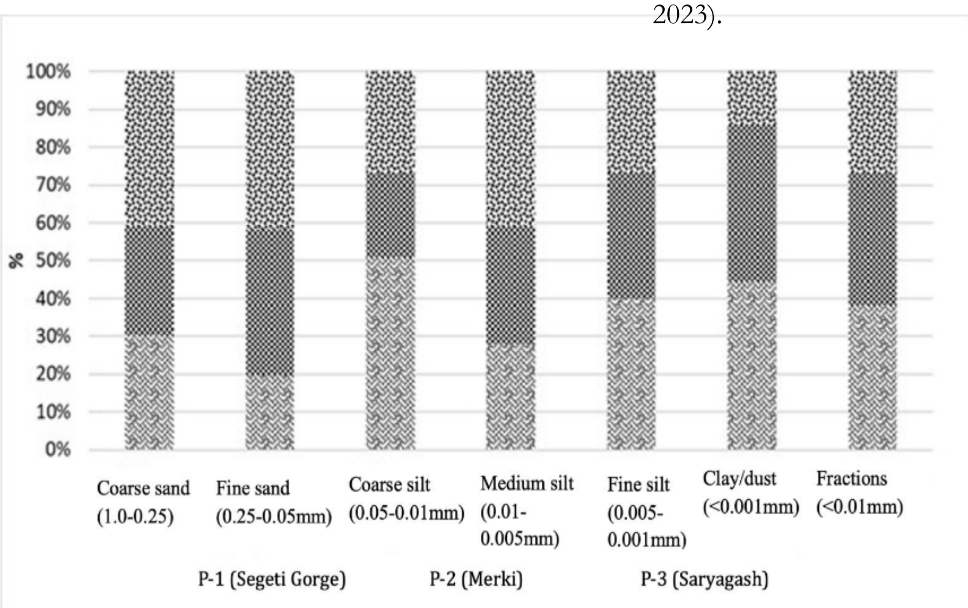


Figure 4 *Granulometric composition of soils*

Chemical properties of soils

The chemical composition of soils in the studied *Capparis herbacea* populations reflects their adaptation to alkaline, carbonate-rich, and nutrient-limited substrates of southern Kazakhstan. Arid and semi-arid soils are generally characterized by high alkalinity, carbonate enrichment, and poor organic matter reserves, which strongly shape their ecological functioning (Naorem et al., 2023; Doménech-Pascual et al., 2025). 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 *Capparis herbacea* to nutrient-deficient environments.

DOI: 10.60923/issn.2281-4485/22936

Population	Parameter	Min	Max	Mean
P1 - Sogeti Gorge	Humus (%)	0.65	6.33	4.01 ± 0.32
	pH	7.85	8.21	7.98 ± 0.07
	CO_2 (%)	0.71	9.65	4.98 ± 0.48
	N (mg/kg)	25.2	50.4	38.03 ± 3.40
	P (mg/kg)	28	56	41.35 ± 3.90
	K (mg/kg)	140	470	304.95± 28
P2 - Merki	Humus (%)	0.18	1.92	1.12 ± 0.09
	pH	8.76	8.96	9.01 ± 0.08
	CO_2 (%)	5.24	12.13	7.89 ± 0.78
	N (mg/kg)	24.5	47.6	35.85± 3.20
	P (mg/kg)	-	7	3.47 ± 0.30
	K (mg/kg)	90	310	198.9 ± 18
P3 - Saryagash	Humus (%)	0.18	2.73	1.46 ± 0.13
	pH	8.04	8.80	8.42 ± 0.08
	CO_2 (%)	5.78	7.97	6.88 ± 0.60
	N (mg/kg)	14.0	50.4	31.8 ± 2.90
	P (mg/kg)	-	28	14.62 ± 1.2
	K (mg/kg)	100	550	324.6 ± 31.2

All mean and SD values were calculated based on three replicates (n = 3) for each parameter.

Table 1
Chemical properties of soils from three *Capparis herbacea* populations in Southern Kazakhstan

In Population 1 (Sogeti Gorge, Ile Alatau), humus content ranged from 0.65% to 6.33% within the 0-70 cm soil profile (Fig. 5). Soil pH values were slightly alkaline (7.85-8.21). Carbonate content (CO_2) varied from 0.71% to 9.65% (Table 1), increasing with depth. Available macronutrients were moderate: nitrogen 25.2-50.4 mg/kg (Fig. 6), phosphorus 28-56 mg/kg, and potassium 140-470 mg/kg. The relatively higher humus and nutrient levels suggest more favorable fertility compared to the other populations, consistent with reports that carbonate-rich mountain soils may retain moderate organic carbon pools (Feng et al., 2023).
In Population 2 (Merki, Kyrgyz Alatau), humus levels were very low (0.18-1.92%). Soils were strongly alkaline, with pH 8.76-8.96 (Fig. 5), and carbonate accumulation was high (5.24-12.13% CO_2). Available nutrients were deficient: nitrogen 24.5-47.6 mg/kg, phosphorus 0-7 mg/kg, and potassium 90-310 mg/kg. These results highlight the nutrient-poor conditions of piedmont soils, where organic matter is scarce and phosphorus particularly limiting, in agreement with observations that salinity and alkalinity often constrain organic matter accumulation (Hasani et al., 2024).
In Population 3 (Saryagash, Turkistan region), humus content ranged from 0.18% to 2.73%. Soil pH was alkaline (8.04-8.80), and carbonates reached 5.78-7.97%. Available nitrogen varied from 14.0-50.4 mg/kg, phosphorus from 0-28 mg/kg, and potassium from 100-550 mg/kg (Fig. 6). Despite generally low fertility, potassium levels were comparatively higher, which is consistent with evidence that arid soils often maintain K reserves even under conditions of low hu-

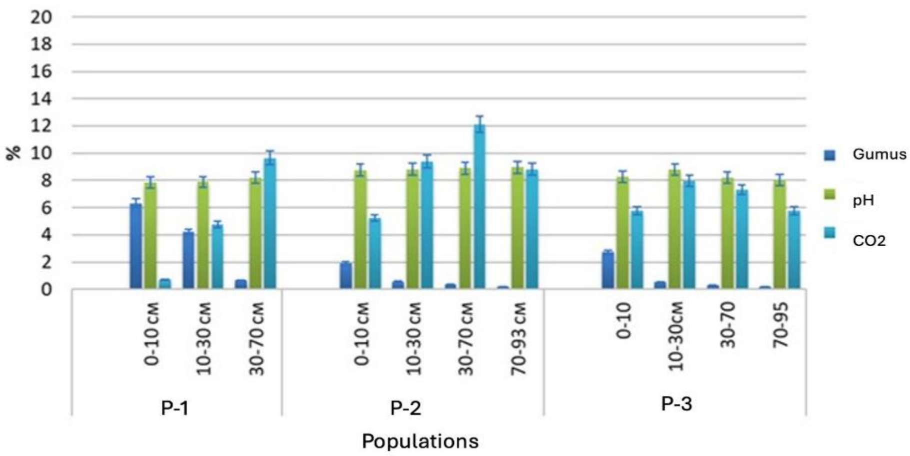


Figure 5
Humus, CO2 and pH indicators in the soil, %

DOI: 10.60923/issn.2281-4485/22936

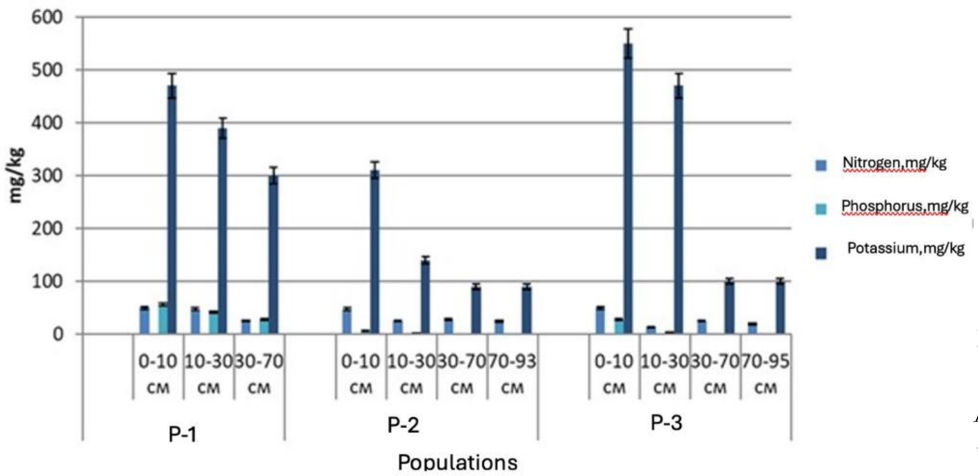


Figure 6
Indicators of mobile nitrogen, phosphorus, potassium in the soil, mg/kg

mus and nitrogen (Naorem et al., 2023). The wide variation in the physical and chemical soil properties observed among the three *Capparis herbacea* populations reflects the strong environmental contrasts across southern Kazakhstan. The study sites differ markedly in elevation (1450-350 m), landscape position (mountain slopes, piedmont alluvial-proluvial fans, and semi-arid lowlands), parent material, and climatic aridity. Mountain soils of Population 1 developed under cooler conditions and active denudation typical of the Northern Tien Shan (Nassyrov et al., 2020), where colluvial deposits create a heterogeneous moisture regime, a wider range of CO_2 concentrations, and greater variability in organic matter. Piedmont soils of Population 2 form on alkaline alluvial–proluvial sediments with limited leaching and intense carbonate accumulation characteristic of the piedmont zone of the Kyrgyz Alatau (Aldazhanova et al., 2022), which naturally results in low humus content, minimal phosphorus availability, and a stable but elevated pH. In contrast, lowland soils of Population 3 are strongly influenced by intense evaporation, shallow groundwater, and aeolian sediment deposition typical of the semi-arid plains of the Turkistan region (Liu et al., 2020), leading to higher salinity and broader fluctuations in nitrogen and carbonate levels. Thus, the observed variability reflects true pedogenic differentiation driven by altitude, climatic aridity, geomorphology, and sedimentation dynamics rather than methodological inconsistencies. Overall, soils of *C.herbacea* are alkaline and carbonate-rich, with low humus and limited nitrogen and phosphorus, though potassium is relatively abundant. These properties reflect weak soil development under arid conditions and confirm the ability of *C.herbacea* to grow in nutrient-poor, alkaline environments (Husein et.al., 2019).

Soil salinity and ionic composition

Kazakhstan is among the countries most affected by soil salinization in Central Asia, where arid climate and intensive irrigation contribute to widespread secondary salinity (Issanova et.al., 2017). Soil salinity is one of the most critical limiting factors for plant growth in arid and semi-arid ecosystems, influencing soil structure, nutrient availability, and water balance (Tarolli, 2024; Stavi et al., 2021). The ionic composition of soils not only reflects the intensity of evaporative processes but also determines plant adaptive strategies in saline environments (Shokri et al., 2024).

In Population 1 (Sogeti Gorge, Ile Alatau), soluble salt content was very low (0.037-0.048%), classifying the soils as non-saline (Table 2). The dominance of bicarbonates (HCO_3^- 0.20-0.28%) and calcium-magnesium cations (Ca^{2+} 0.45-0.63%; Mg^{2+} 0.18-0.45%) indicates stable soil structure and limited salinity stress. Such conditions are typical for mountain soils where leaching processes exceed salt accumulation, maintaining favorable environments for vegetation establishment (Khasanov et.al., 2023).

In Population 2 (Merki, Kyrgyz Alatau), total salt content slightly increased (0.042-0.062%) but remained within the non-saline category. The prevalence of bicarbonates (0.44-0.48%) over chlorides (0.03-0.10%) and sulfates (0.03-0.38%) reflects the piedmont position of these soils, where moderate drainage reduces the risk of salinization. Nevertheless, nutrient availability is constrained by high alkalinity and low organic matter, a common feature of piedmont soils in arid Central Asia (Navarro-Torre et al., 2023).

In Population 3 (Saryagash, Turkistan region), soils ex-

DOI: 10.60923/issn.2281-4485/22936

Table 2. Soil salinity and ionic composition of *Capparis herbacea* populations

Population	Salt content	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
Population 1 (Sogeti Gorge, Ile Alatau)	0,037-0,048	0,20-0,28	0,03-0,08	0,12-0,26	0,45-0,63	0,18-0,45	0,03-0,14	0,011
Population 2 (Merki, Kyrgyz Alatau)	0,042-0,062	0,44-0,48	0,03-0,10	0,03-0,38	0,27-0,45	0,18-0,45	0,03	-
Population 3 (Sarya-gash,Turkistan region)	0,082-0,910	0,28-0,44	0,03-0,07	0,69-13,15	0,63-12,15	0,45-1,18	0,03-0,14	0,28

hibited clear signs of salinity, with total salt content ranging from 0.082% to 0.910%. Here, sulfates (SO_4^{2-} 0.69-13.15%) and calcium (0.63-12.15%) were dominant, while bicarbonates (0.28-0.44%) and magnesium (0.45-1.18%) played secondary roles. The classification of upper horizons as moderately saline and deeper layers as strongly saline indicates processes of secondary salinization, driven by shallow groundwater and high evaporation rates (Devkota et al., 2015). Such ionic patterns are typical of semi-arid lowlands where evapotranspiration exceeds precipitation, intensifying salt accumulation (Shokri et al., 2024). Overall, Populations 1 and 2 remain non-saline, while Population 3 demonstrates moderate to strong salinity. These differences highlight the ecological plasticity of *C.herbacea*, which can persist under both carbonate-rich, non-saline soils and sulfate-dominated saline environments, confirming its adaptation to heterogeneous edaphic conditions in southern Kazakhstan (Rahman et.al., 2021).

Conclusions

This study provides a comprehensive characterization of the soils associated with *Capparis herbacea* Willd. in southern Kazakhstan. Across three populations, soils were generally alkaline, carbonate-rich, and nutrient-poor, yet supported stable stands of the species. Populations 1 and 2 were associated with carbonate soils of non-saline character, whereas Population 3 was distinguished by higher salinity and sulfate enrichment, reflecting the stronger influence of evaporation and shallow groundwater. Among the studied sites, Population 3 clearly differed from Populations 1 and 2 by exhibitting pronounced salinity and altered ionic composition. In contrast, Populations 1 and 2 shared more favorable carbonate-rich but non-saline conditions. Despite these constraints, *C.herbacea* demonstrated marked ecological plasticity, persisting under both favorable and stressful edaphic conditions. This adaptability highlights its importance as an indicator species of soil quality and a promising candidate for land restoration initiatives in degraded arid and semi-arid ecosystems of Central Asia.

References

ABOELSOUD H.M., HABIB A., ENGEL B., HASHEM A.A., ABOU EL-HASSAN W., GOVIND A., ELNASHAR A., EID M., KHEIR A.M.S. (2023) The combined impact of shallow groundwater and soil salinity on evapotranspiration using remote sensing in an agricultural alluvial setting. Journal of Hydrology: Regional Studies, 47:101372. https://doi.org/10.1016/j.ejrh.2023.101372

ACADEMY OF SCIENCES OF THE KAZAKH SSR, Institute of Botany (1969) Illustrated plant identification guide of Kazakhstan. Vols. 1–2. Nauka, Alma-Ata.

ACADEMY OF SCIENCES OF THE KAZAKH SSR, Institute of Botany (1956-1966) Flora of Kazakhstan. Vols. 1-9. Alma-Ata: Academy of Sciences of the Kazakh SSR.

ADENOVA D., SARSEKOVA D., ABSAMETOV M., MURTAZIN Y., SAGIN J., TRUSHEL L., MIROSHNICHENKO O. (2024) The study of groundwater in the Zhambyl Region, Southern Kazakhstan, to improve sustainability. *Sustainability*, 16(11):4597. https://doi.org/10.3390/su16114597

ALDAZHANOVA G., BEISSENOVA A., SKORINTSEVA I., MUSTAFAYEV Z., ALIASKAROV D. (2022) Assessment of land resources of the Zhambyl Region as the basis of recreation development and food security of the Republic of Kazakhstan. *GeoJournal of Tourism and Geosites*, 44(4):1183–1189. https://doi.org/10.30892/gtg.44401-933

ALEXANDROVA L.N., NAIDENOVA O.A. (1986) *Laboratory and Practical Work in Soil Science*. Agropromizdat, Moscow.

ARALOVA D., KARIYEVA J., KHUJANAZAROV T., TODERICH K. (2018) Drought variability and land degradation in Central Asia: assessment using remote sensing data and drought indices. In: Egamberdieva D., Öztürk M. (eds) *Vegetation of Central Asia and Environs*. Springer, Cham. https://doi.org/10.1007/978-3-319-99728-5_2

ARINUSHKINA E.V. (1977) *A Guide to Soil Chemical Analysis*. Moscow State University Press, Moscow.

BOBKOVA Y. (2008) *Methods of Soil and Agrochemical Research*. OGAU Press, Oryol.

CHADRAOUI S., ABI-RIZK A., EL-BEYROUTHY M., CHALAK L., OUAINI N., RAJJOU L. (2017) *Capparis*

DOI: 10.60923/issn.2281-4485/22936

spinosa L. in a systematic review: a xerophilous species of multi values and promising potentialities for agrosystems under the threat of global warming. *Frontiers in Plant Science*, 8:1845. https://doi.org/10.3389/fpls.2017.01845

DAI J.Y., CHENG S.T. (2022) Modeling shallow soil moisture dynamics in mountainous landslide active regions. Frontiers in Environmental Science, 10:913059. https://doi.org/10.3389/fenvs.2022.913059

DEVKOTA M., MARTIUS C., GUPTA R.K., DEVKOTA K.P., MCDONALD A.J., LAMERS J.P.A. (2015) Managing soil salinity with permanent bed planting in irrigated production systems in Central Asia. Agriculture, Ecosystems and Environment, 202:90–97. https://doi.org/10.1016/j.agee.2014.12.006

DOMÉNECH-PASCUAL A., CHAVEZ RODRIGUEZ L., HAN X., CASAS-RUIZ J.P., FERRIOL-CIURANA J., DONHAUSER J., JORDAAN K., ALLISON S.D., FROSSARD A., PRIEMÉ A., RAMOND J.B., ROMANÍ A.M. (2025) Soil functions are shaped by aridity through soil properties and the microbial community structure. Applied Soil Ecology, 213:106313. https://doi.org/10.1016/j.apsoil.2025.106313

DOU X., MA X., ZHAO C., LI J., YAN Y., ZHU J. (2022) Risk assessment of soil erosion in Central Asia under global warming. Catena, 212:106056. https://doi.org/10.1016/j.catena.2022.106056

DUNIWAY M.C., PETRIE M.D., PETERS D.P.C., ANDERSON J.P., CROSSLAND K., HERRICK J.E. (2018) Soil water dynamics at 15 locations distributed across a desert landscape: insights from a 27-yr dataset. *Ecosphere*, 9(7):e02335. https://doi.org/10.1002/ecs2.2335

EGLI M., FITZE P. (2001) Quantitative aspects of carbonate leaching of soils with differing ages and climates. Catena, 46(1):35–62. https://doi.org/10.1016/S0341-8162(01)00154-0

FENG W., JIANG J., LIN L., WANG Y. (2023) Soil calcium prompts organic carbon accumulation after decadal saline-water irrigation in the Taklamakan desert. Journal of Environmental Management, 344:118421. https://doi.org/10.1016/j.jenvman.2023.118421

FLOWERS T.J., COLMER T.D. (2008) Salinity tolerance in halophytes. New Phytologist, 179(4):945–963. https://doi.org/10.1111/j.1469-8137.2008.02531.x

GNANN S., BALDWIN J.W., CUTHBERT M.O., GLEESON T., SCHWANGHART W., WAGENER T. (2025) The influence of topography on the global terrestrial water cycle. Reviews of Geophysics, 63(1):e2023RG000810. https://doi.org/10.1029/2023RG000810

GOST 12536-2014. (2014) Soils. Methods of laboratory granulometric (grain-size) and microaggregate distribution [in Russian]. Moscow: Standardinform.

GOST 23740-79. (1979) Soils. Methods for determination of humus content [in Russian]. Moscow: Standardinform.

GOST 26205-91. (1991) Soils. Determination of mobile compounds of nitrogen, phosphorus and potassium [in Russian]. Moscow: Standardinform.

GOST 26423-85. (1985) Soils. Methods for determination of specific electrical conductivity, pH and solid residue of water extract [in Russian]. Moscow: Standardinform.

GOST 26425-85. (1985) Soils. Methods for determination of carbonate content [in Russian]. Moscow: Standardinform.

HASANI A., SMITH P., SHOKRI N. (2024) Negative correlation between soil salinity and soil organic carbon variability. Proceedings of the National Academy of Sciences USA, 121(18):e2317332121. https://doi.org/10.1073/pnas.2317332121

HU Y., HAN Y., ZHANG Y. (2020) Land desertification and its influencing factors in Kazakhstan. Journal of Arid Environments, 180:104203. https://doi.org/10.1016/j.jaridenv.2020.104203

HUSEIN H., MOUSA M., SAHWAN W., BÄUMLER R., LUCKE B. (2019) Spatial distribution of soil organic matter and soil organic carbon stocks in semi-arid area of Northeastern Syria. Natural Resources, 10(12):415–432. https://doi.org/10.4236/nr.2019.1012028

IBM CORP. (2024) IBM SPSS Statistics for Windows, Version 28.0. IBM Corp., Armonk, NY.

ISSANOVA G.T., ABUDUWAILI J., MAMUTOV Z.U. et al. (2017) Saline soils and identification of salt accumulation provinces in Kazakhstan. Arid Ecosystems, 7:243–250. https://doi.org/10.1134/S2079096117040035

IUSS (2022) World Reference Base for Soil Resources. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. 4th Edition. International Union of Soil Sciences (IUSS), Vienna. https://files.isric.org/public/documents/WRB_fourth_edition_2022-12-18.pdf

JIANG L., BAO A., JIAPAER G., LIU R., YUAN Y., YU T. (2022) Monitoring land degradation and assessing its drivers to support Sustainable Development Goal 15.3 in Central Asia. Science of the Total Environment, 807(2):150868. https://doi.org/10.1016/j.scitotenv.2021.150868

JULIEV M., JUMANIYAZOV I., TOGAEV I., TOSHTEMIROV S., SAMIEV A., OCHILOV I., USMANOV K., SAIDOVA M. (2023) Land degradation in Central Asia: a review of papers from the Scopus database published in English for the period of 2000–2023. E3S Web of Conferences, 462:03020. https://doi.org/10.1051/e3sconf/202346203020

KAKABAYEV A.A., SHARIPOVA B.U., BARANOVSKAYA N.V., RODRIGO-ILARRI J., RODRIGO-CLAVERO M.-E., LO PAPA G., BAZILEVSKAYA E.A., MURATBEKOVA S., NURMUKHANBETOVA N.,

DOI: 10.60923/issn.2281-4485/22936

DURMEKBAYEVA S., TOYCHIBEKOVA G.B., KURMANBAYEV R., ZHUMABAYEVA A. (2024) Impact of environmental conditions on soil geochemistry in southern Kazakhstan. Sustainability, 16(15):6361. https://doi.org/10.3390/su16156361

KHASANOV S., KULMATOV R., LI F., VAN AMSTEL A., BARTHOLOMEUS H., ASLANOV I., SULTONOV K., KHOLOV N., LIU H., CHEN G. (2023) Impact assessment of soil salinity on crop production in Uzbekistan and its global significance. Agriculture, Ecosystems and Environment, 342:108262. https://doi.org/10.1016/j.agee.2022.108262

KOROLYUK T.V. (2012) Soil interpretation of space images in CPC systems. In: Digital Soil Cartography: Theoretical and Experimental Studies. Soil Institute named after V.V. Dokuchaev, Moscow, pp. 124–140.

LI N., SKAGGS T.H., ELLEGAARD P., BERNAL A., SCUDIERO E. (2024) Relationships among soil moisture at various depths under diverse climate, land cover and soil texture. Science of the Total Environment, 947:174583. https://doi.org/10.1016/j.scitotenv.2024.174583

LIU W., MA L., SMANOV Z., SAMARKHANOV K., ABUDUWAILI J. (2022) Clarifying soil texture and salinity using local spatial statistics (Getis-Ord Gi* and Moran's I) in Kazakh–Uzbekistan border area, Central Asia. Agronomy, 12(2):332. https://doi.org/10.3390/agronomy12020332

LIU Y., WANG P., RUAN H., WANG T., YU J., CHENG Y., KULMATOV R. (2020) Sustainable use of groundwater resources in the transboundary aquifers of the five Central Asian countries: challenges and perspectives. Water, 12(8):2101. https://doi.org/10.3390/w12082101

LU H., BURBANK D.W., LI Y. (2010) Alluvial sequence in the north piedmont of the Chinese Tian Shan over the past 550 kyr and its relationship to climate change. Palaeogeography, Palaeoclimatology, Palaeoecology, 285(3–4):343–353. https://doi.org/10.1016/j.palaeo.2009.11.031

MAMUROVA A., KAIRANOVA G., ZAPARINA Y., MENGTAY A., KUDAIBERGENOVA A., YEDILOVA A., KALIYEV B. (2025a) Soil morphological and physico-chemical characteristics of Zygophyllum fabago L. populations in the Ili-Balkhash region of Kazakhstan. EQA – International Journal of Environmental Quality, 70:106–115. https://doi.org/10.6092/issn.2281-4485/22033

MAMUROVA A., KAIRANOVA G., AMERTAYEVA G., AKHTAYEVA N., BEYATLI A., KIYEKBAYEVA L., ISKAKOVA Z., ZHALDYBAEV K. and ZHUMALINA K. (2025b) Phytochemical profiling and antioxidant properties of Ajania fastigiata (C. Winkl.) Poljakov (Asteraceae). Farmacia, 73(4): 1038–1046. https://doi.org/10.31925/farmacia.2025.4.23

MAMUROVA A., KAIRANOVA G., BEYATLI A., SMAGULOVA G., YEDILOVA A., ZHALDYBAYEV K., ZHUMALINA K. and TOREGELDIYEVA A. (2025c)) Phytochemical analysis and antioxidant, antimicrobial, cytotoxic activities of different solvent extracts of Zygophyllum fabago L. Brazilian Journal of Biology, 85: e293666. https://doi.org/10.1590/1519-6984.293666

MUNNS R., TESTER M. (2008) Mechanisms of salinity tolerance. Annual Review of Plant Biology, 59:651–681. https://doi.org/10.1146/annurev.arplant.59.032607.092911

MUSSINA A., TURSYNGALI M., DUSKAYEV K., RODRIGO-ILARRI J., RODRIGO-CLAVERO M.-E., ABDULLAYEVA A. (2025) Forecasting channel morpho-dynamics in the Ulken Almaty River (Ile Alatau, Kazakh-stan). Water, 17(13):2029. https://doi.org/10.3390/w1713.2029

MUSSINA A., RAIMBEKOVA Z., SHAHGEDANOVA M., BARANDUN M., NARBAEVA K., ABDULLAYEVA A., NYSSANBAYEVA A. (2023) Mountain resilience: a tool for mudflow risk management in the Ile Alatau Mountains, Kazakhstan. Mountain Research and Development, 43(1) :D1–D10. https://doi.org/10.1659/mrd-journal-D-22-00004

MUSTAFAYEV Z., TOLETAYEV A., SKORINTSEVA I., ALDAZHANOVA G. (2023) Assessment of natural moisture availability of Turkestan region of the Republic of Kazakhstan. Indonesian Journal of Geography, 55(2):352–360. https://doi.org/10.22146/ijg.79703

NAOREM A., JAYARAMAN S., DANG Y.P., DALAL R.C., SINHA N.K., RAO C.S., PATRA A.K. (2023) Soil constraints in an arid environment—challenges, prospects, and implications. Agronomy, 13(1):220. https://doi.org/10.3390/agronomy13010220

NASSYROV N.B., BAYSEITOV N.K., SRAMKO G. (2020) Geobotanical description and ecology of the population of the endemic species Galatella saxatilis Novopokr. in Syugaty mountain gorge. Eurasian Journal of Ecology, 65(4). https://doi.org/10.26577/EJE.2020.v65.i4.05

NAVARRO-TORRE S., GARCIA-CAPARRÓS P., NOGALES A., ABREU M.M., SANTOS E., CORTINHAS A.L., CAPERTA A.L. (2023) Sustainable agricultural management of saline soils in arid and semi-arid Mediterranean regions through halophytes, microbial and soil-based technologies. Environmental and Experimental Botany, 212:105397. https://doi.org/10.1016/j.envexpbot.2023.105397

RAHMAN M.M., MOSTOFA M.G., KEYA S.S., SIDDIQUI M.N., ANSARY M.M.U., DAS A.K., RAHMAN M.A., TRAN L.S.-P. (2021) Adaptive mechanisms of halophytes and their potential in improving salinity tolerance in plants. International Journal of Molecular Sciences, 22(19):10733. https://doi.org/10.3390/ijms221910733

RAVI S., D'ODORICO P., BRESHEARS D.D., FIELD J.P., GOUDIE A.S., HUXMAN T.E., LI J., OKIN G.S., SWAP R.J., THOMAS A.D., VAN PELT S., WHICKER J.J., ZOBECK T.M. (2011) Aeolian processes and the biosphere. Reviews of Geophysics, 49(3):RG3001. https://doi.org/10.1029/2010RG000328

DOI: 10.60923/issn.2281-4485/22936

ROY R.N., FINCK A., BLAIR G.J., TANDON H.L.S. (2006) Plant Nutrition for Food Security: A Guide for Integrated Nutrient Management. Food and Agriculture Organization of the United Nations, Rome. Available from: https://www.fao.org/3/a0250e/a0250e00.htm

ROZANOV B.G. (2004) Soil Morphology. Academic Project, Moscow, 432 p.

SAXTON K.E., RAWLS W.J. (2006) Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Science Society of America Journal, 70(5):1569–1578. https://doi.org/10.2136/sssaj2005.0117

SHOKRI N., HASSANI A., SAHIMI M. (2024) Multi-scale soil salinization dynamics from global to pore scale: a review. Reviews of Geophysics, 62(3):e2023RG000804. https://doi.org/10.1029/2023RG000804

SOIL SURVEY STAFF (2022) Keys to Soil Taxonomy. 13th Edition. USDA – Natural Resources Conservation Service, Washington, DC. https://www.nrcs.usda.gov/sites/default/files/2022-09/Keys-to-Soil-Taxonomy.pdf

STAVI I., THEVS N., PRIORI S. (2021) Soil salinity and sodicity in drylands: a review of causes, effects, monitoring, and restoration measures. Frontiers in Environmental Science, 9:712831. https://doi.org/10.3389/fenvs.2021.712831

ŚWITONIAK M., MICHALSKI A., MARKIEWICZ M. (2022) Classification of alluvial soils – problematic issues on the examples from South Baltic Lakelands, north Poland. Soil Science Annual, 73(3):157099 https://doi.org/10.37501/soilsa/157099

TAROLLI P., LUO J., PARK E., BARCACCIA G., MASIN R. (2024) Soil salinization in agriculture: Mitigation and adaptation strategies combining nature-based solutions and bioengineering. Science, 27(2):108830. https://doi.org/10.1016/j.isci.2024.108830

TLEUBERLINA O., MAMUROVA A., ISKAKOVA Z., AIBULDINOV Y., KOLPEK A., KOPISHEV Y., SATBAEVA G., MUKAZHANOVA Z., KURMANBAYEVA M. (2023a) Evaluation of the Capparis herbacea Willd's chemistry, antioxidant and cytotoxic activity. Anti-Inflammatory & Anti-Allergy Agents in Medicinal Chemistry, 22(4):261–272. ttps://doi.org/10.2174/0118715230281697231115074426

TLEUBERLINA O.B., MAMUROVA A.T., OSMONALI B., OMAROVA G.K. (2023b) Distribution and geobotanical studies of the medicinal plant Capparis herbacea Willd. in the southern regions of Kazakhstan. Experimental Biology, 94(1). https://doi.org/10.26577/eb.2023.v94.i1.04

TLEUOVA Z., SNOW D.D., MUKHAMEDZHANOV M., ERMENBAY A. (2023) Relation of hydrogeology and contaminant sources to drinking water quality in southern Kazakhstan. Water, 15(24):4240. https://doi.org/10.3390/w15244240

WANG L., FAN L., ZHAO Z., ZHANG Z., JIANG L., CHAI M., TIAN C. (2022) The *Capparis spinosa* var. *herbacea* genome provides the first genomic instrument for a diversity and evolution study of the Capparaceae family. GigaScience, 11:giac106. https://doi.org/10.1093/gigascience/giac106

WANG Q., ZHANG H.-X. (2022) Population genetic structure and biodiversity conservation of a relict and medicinal subshrub Capparis spinosa in arid Central Asia. Diversity, 14(2):146. https://doi.org/10.3390/d14020146

WANKMÜLLER F.J.P., DELVAL L., LEHMANN P., et al. (2024) Global influence of soil texture on ecosystem water limitation. Nature, 635:631–638. https://doi.org/10.1038/s41586-024-08089-2

YANG F., ZHANG G.L., YANG F., YANG R.M. (2016) Pedogenetic interpretations of particle-size distribution curves for an alpine environment. Geoderma, 282:9–15. https://doi.org/10.1016/j.geoderma.2016.07.003

YEDILOVA A., INELOVA Z., ZHAMANBAYEVA M., KIYEKBAYEVA L., YERUBAYEVA G., SARSEMBAYEVA A., BAITASHEVA G., ASHIROVA Z., NAZARBEKOVA S., SATYBALDIYEVA G. and BAUYRZHAN T. (2025) Evaluating the status of Humulus lupulus populations in Kazakhstan: Implications for conservation, sustainability, and forest ecosystem management. ES Energy and Environment, 27: 1426. https://dx.doi.org/10.30919/ee1426

ZÁDOROVÁ T., PENÍŽEK V., KOUBOVÁ M., LISÁ L., PAVLŮ L., TEJNECKÝ V., ŽÍŽALA D., DRÁBEK O., NĚMEČEK K., VANĚK A., KODEŠOVÁ R. (2023) Formation of Colluvisols in different soil regions and slope positions (Czechia): Post-sedimentary pedogenesis in colluvial material. Catena, 229:107233. https://doi.org/10.1016/j.catena.2023.107233

ZÁDOROVÁ T., PENÍŽEK V. (2018) Formation, morphology and classification of colluvial soils: a review. European Journal of Soil Science, 69(4):577–591. https://doi.org/10.1111/ejss.12673

ZHANG H., MA Z.F. (2018) Phytochemical and - properties of *Capparis spinosa* as a medicinal plant. Nutrients, 10(2):116. https://doi.org/10.3390/nu10020116

ZHANG R., QIN L., SHANG H., et al. (2020) Climatic change in southern Kazakhstan since 1850 C.E. inferred from tree rings. International Journal of Biometeorology, 64:841–851. https://doi.org/10.1007/s00484-020-01873-5

ZHAO S., ZHAO X., LI Y., CHEN X., LI C., FANG H., LI W., GUO W. (2023) Impact of deeper groundwater depth on vegetation and soil in semi-arid region of eastern China. Frontiers in Plant Science, 14:1186406. https://doi.org/10.3389/fpls.2023.1186406