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The Soils of Natural (In Situ) Coenopopulations of *Taraxacum kok-saghyz* L.E. Rodin in Kazakhstan

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Abstract: This article studies the morphological and physicochemical properties of soils in the natural habitat of dandelion kok-saghyz (*Taraxacum kok-saghyz* L.E. Rodin) (TKS)—a source of high-quality rubber. The purpose of the work is to study the natural soil habitat of dandelion TKS in comparison with the nearby area where TKS is absent. The methods of soil research are comparative, geographical, morphological, and analytical. Soil sections were laid down and georeferenced, and relief, vegetation, and morphological structures of soil profiles by genetic horizons were described. A database of the physical and chemical properties of soils by horizon was created. Landscapes and soil conditions of in situ populations have been studied in the Kegen District of the Almaty region in the territory of the Kegen River floodplain, in the areas of the Jalauly and Kegen villages, and in the zone of groundwater inclination north of Saryzhas village. The natural soil habitat of TKS was studied. It was found that TKS grows in conditions of moisture floodplains of intermountain valleys on saline floodplain meadowy soils of a sulfate–sodium composition with a high content of total humus and nutrient elements in an alkaline environment.

Keywords: TKS; soil cover; soil type and subtype; genetic horizon; morphological structure; physical and chemical properties

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1. Introduction

Applicability. Natural rubber (NR, cis-1,4-polyisoprene) is an essential high molecular weight biopolymer that is a critical, non-flammable raw material vital to industries such as transportation, medicine, and defense. Its unique physical properties include high elasticity, resilience, resistance to impact and abrasion, efficient heat dissipation, and plasticity at low temperatures, making NR an important raw material for many different rubber and latex products. NR is used to produce more than 50,000 rubber products, including aircraft and automobile tires, surgical gloves, contraceptives, footwear, apparel, and other products [1].

The global market of natural rubber (NR) was approximately US $24 billion in 2016, with an NR consumption of 12.9 million tons, which is projected to increase up to 16.5 million tons by 2023 (International Rubber Study Group—IRSG). Total demand for natural rubber is on the rise and could reach US $68.5 billion by 2026 [2].

Currently, the Para rubber tree (*Hevea brasiliensis* (Willd. ex A. Juss.)) grown in tropical plantations is the only source of commercially produced NR. That is due to the fact that NR from plants is outperforming petroleum rubber in several parameters, e.g., the NR polymer has a much higher molecular weight than synthetic rubber, and the sustainable and renewable production of plant rubber is considered to be more efficient and environmentally friendly than the refining of non-renewable oil [3,4].

Nevertheless, alternative sources and systems for rubber production are needed to increase the biological and geographical diversity of NR production, especially because of the need for *H. brasiliensis* for special growth conditions and its vulnerability to various infectious diseases. One threat to *Hevea brasiliensis* rubber production is South American Leaf Phytophthorosis (SALB) caused by the fungus *Pseudocercospora ulei*, which has affected traditional rubber production in South America since 1934. This disease can spread to *H. brasiliensis* trees in Southeast Asia, which are genetically very similar to each other and to trees in South America [5].

The study of alternative plant species—sources of NR, such as dandelion kok-saghyz (*Taraxacum kok-saghyz* L.E. Rodin), (TKS), and guayule (*Parthenium argentatum*), and or in vitro NR production systems—is ongoing [6]. The perennial herbaceous plant TKS is generally recognized as an alternative, complementary of *H. brasiliensis,* a source of high-quality NR, and a promising crop for ex situ cultivation in temperate climate zones, where the traditional NR source tropical tree *H. brasiliensis* does not take root. TKS has attracted attention due to its NR content as a strategic biomaterial and a promising, sustainable, and renewable alternative to synthetic rubber from fossil fuel carbon sources. NR of TKS is as good as NR of *H. brasiliensis*.

Moreover, NR TKS is a source of polysaccharide inulin, with 25 to 40% of dry weight mass. The expensive polysaccharide inulin is used in the pharmaceutical and food industries [7,8].

TKS has been actively studied in countries with moderate climates, such as the Czech Republic, the UK, Germany, Italy, China, South Korea, Kazakhstan, the Russian Federation, and the USA [6,9–15].

The German automobile tire brand 'Continental AG' announced that it plans to start production of "the first bicycle tire made from sustainable rubber of TKS", which it intended to be grown on the premises of its own factories, avoiding some of the traditional problems with *H. brasiliensis* latex that come as a result of the extended time between planting and growing (just six months for the dandelion, compared with seven years for the rubber tree) and fluctuating prices for the rubber due to long transportation distances between places where rubber can be grown and the company's production facilities in Europe [16].

TKS is widespread in the intermountain valleys of the Tien Shan and is included in the Red Book of Kazakhstan. Measures are needed to revive and broaden the degrading populations of TKS. It is important to conduct comparative studies of soils with actively growing TKS and soils where TKS is absent or does not grow.

In the area of TKS's natural growth in the Tien Shan intermountain valleys, it is biologically viable, its coenopopulations are resistant to self-sustaining, the average NR content in the roots of TKS is 21%, and the highest content reaches 41%. The NR content in roots of TKS plant samples is 14.00% in "Kegen", 22.19% in "Tuzkol", and 29.18% in "Tekes" populations. [17,18].

Based on these present ideas, the higher NR content in the roots of TKS plants under in situ conditions positively correlates with high expression levels of a number of genes directly involved in NR synthesis, indicating that NR production is strictly controlled at the level of transcription [8].

In conditions of introduction (ex situ), however, the NR content in the roots of TKS decreases, for example, up to 7.66% in South Korea [13]. Without human care, TKS becomes non-viable, cannot survive competition with weeds, and will become extinct. Consequently, it is necessary to search for ways to increase the productivity of TKS in introductory conditions [15].

It is assumed that high survivability, high competitive ability relative to other plant species, and the highest NR content in the roots of TKS are achieved by the peculiarities of the natural soil habitat of this endemic plant species. On this subject, it is necessary to arrange a regional assignment of TKS considering the soil and climatic conditions of the intermountain valleys of the Tien Shan and the natural habitat of this endemic and rare species.

It is notable that the in situ soil description of *T. kok-saghyz* populations in the publications of a number of authors [8,19–21] is not presented in detail, and at present, it is necessary to more thoroughly study the current state of the natural soil environment of TKS.

TKS is a polymorphic species, especially in leaf shape, width, and ability to be cut. However, these forms are very unstable. TKS ecotypes have been identified. These are xeromorphic, hydromorphic, and mesomorphic in between. TKS is a young, progressive endemic species [18].

Numerous species close to TKS from the genus Taraxacum of dandelions, very common weeds in the world, found in a wide variety of conditions, do not have the ability to form rubber in any significant quantities. Consequently, the natural conditions of the areas where TKS currently grows wild in fairly large numbers are the environment that determines the formation of the main biological properties that distinguish TKS from its relatives [19].

The territory that includes the TKS range is approximately 5–8 thousand km^2. However, most of this territory is featured by soil variations and vegetation that exclude the possibility of the existence of TKS. According to previous data, nearly 2000 hectares are covered with natural TKS thickets. The TKS habitat is connected by the intermountain valleys of the Eastern Tien Shan, located in the Kegen District—in the Tekes, Sarjas, Kegen, Karkarin, Cheldysu, and Ashily valleys. The lowest point at which TKS is located is 1850 m above the sea level, and the highest is 2100 m above the sea level [18].

The main factor in the distribution of TKS over its range is soils. TKS is distributed on intrazonal hydrogenous, fertile soils in the form of more or less large thickets that are part of the complex that makes up the dry steppe belt, which includes all the valleys that are the habitat of the rubber plant. All soils under natural TKS cenoses are saline, with the degree of salinity varying from a fraction of a percent to 5–6%. For the most part, they belong to meadow alkaline solonchaks and partly to dry steppe solonchaks of loamy mechanical composition, up to plump, as well as coarse skeletal ones, located near salty springs. Dark gray soils, various wet, swampy soils, chernozem-like soils lying on the bottoms of ravine depressions, coarse skeletal soils located near fresh springs, takyrs, and variegated clays are not common for *T. kok-saghyz* [19–22].

The purpose of this work is to study the natural soil habitat of dandelion TKS in comparison with the nearby area where TKS is absent.

2. Materials and Methods

This study is based on the comparative geographical method [23]. Field studies were performed using the key transect method [24]. Morphological methods were used at the stage of route field studies [25] to ensure authenticity and feasibility of field diagnostics of soils and characteristics of the main morphological properties of soils. Morphological description of the soil section includes coordinates, section number, name–type, subtype, genus, section depth, thickness of humus horizons A + B, exposure, slope, type of relief, depth of underlying dense rocks, boiling depth, depth of carbonates, salts, gypsum, type of plant community, landscape-forming plants, projective cover and height of vegetation cover, and type of parent rock.

Testing of soil samples was carried out according to generally accepted methods of the countries of the Commonwealth of Independent States, including the Republic of Kazakhstan, in an accredited laboratory of the Kazakh Research Institute of Soil Science and Agrochemistry named after U.U. Uspanov [26,27]. To characterize physicochemical properties of the soil, the content of total humus and nitrogen, CO_2, absorbed calcium, magnesium, sodium and potassium, pH of aqueous suspension, mobile forms of nitrogen, phosphorus, potassium, composition of easily soluble salts, and granulometric composition of the soil were determined.

Four soil profile cuts were laid across small populations of TKS with an area of 3–5 square meters, and another four soil profile cuts were laid within a short distance of populations where TKS is absent.

3. Results

Soil is a natural formation consisting of soil horizons formed as a result of the transformation of surface layers of the lithosphere under the influence of water, air, and living organisms.

Morphological features generally accepted in soil science are as follows: coloring, structure, composition, granulometric texture, new formations and inclusions, structure, and thickness of the soil profile.

Alluvial meadowy alkaline soils in the studied area are formed within the floodplain of the Kegen River under grass–forb meadows at absolute altitudes from 1798 m of "Zhalauly" to 1962 m of Tuzkol Lake. Parent rock materials are basically loess-like loams, and in some places, there are red-colored clays, Paleogene–Neogene, and crushed stony sediments. Boiling of soil carbonates from HCI—from the surface. Visible carbonates appear in the lower part of the humus and underhumus horizons.

The location of soil profiles in areas of natural vegetation of the TKS is presented in Figure 1.

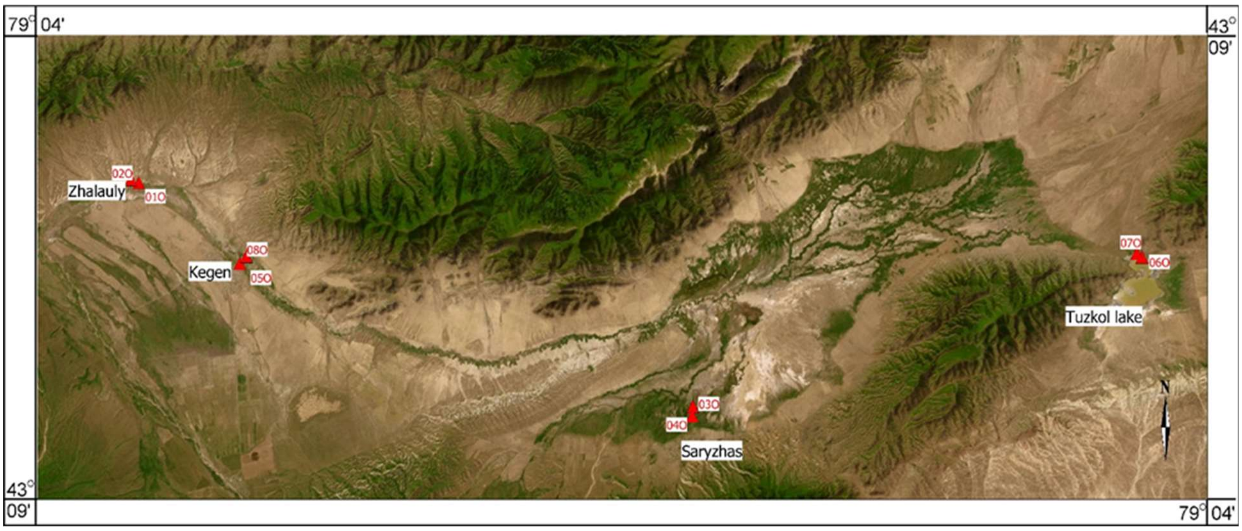

Figure 1. Location of soil profiles at natural vegetation sites of *T. kok-saghyz*. Profiles 01O, 03O, 05O, and 06O with TKS population, and 02O, 04O, 0.7O, and 08O without TKS. Settlements: Zhalauly, Kegen, Saryzhas, and Lake Tuzkol.

Morphogenetic features and physicochemical properties of the studied soils' in situ populations of TKS in comparison with the nearby area where TKS is absent.

Soil profile cut 01O—alluvial meadowy alkaline middle loamy soil of TKS population "Zhalauly" (43°4′12.67″ 79°9′9.76″, H = 1798 m). The floodplain of the Kegen River is directly at the riverbank. The soil profile is cut on the ground surface (Figure 2). Mixed herbs–sedgy vegetation: *Carex* [28], *Artemisia* [29], *Achillea* [30], and *Taraxacum* [31]. Projective cover 100%. Plants 3–5 cm are eaten by cattle. Effervescence from HCl starting from 10 cm. Salts from 10 cm, numerous fibers. Depth 100 cm. Humus-accumulated horizon (A + B) 27 cm.

The upper soddy soil horizon (A_1^s = 0–10 cm) is a brownish-darkish-gray, fresh, compacted, strongly radiculose, granulated, medium loam soil. The lower horizon (B_1^{sk} = 10–27 cm) is gray with numerous salt fibers, compacted with sparse roots, and is a sharply ribbed, granulated, medium loam soil. The carbonate soil horizon (B_C^{CK} = 27–57 cm) is grayish-white with salt fibers and freshly compacted, clumpy clay loam. The buried soil horizon (B_1^{bur} = 57–80 cm) is dark gray, freshly compacted, clumpy, clay loam. The soil horizon (C = 80–100 cm) is silty-whitish whitish-light gray, moisty, compacted light loamy soil.

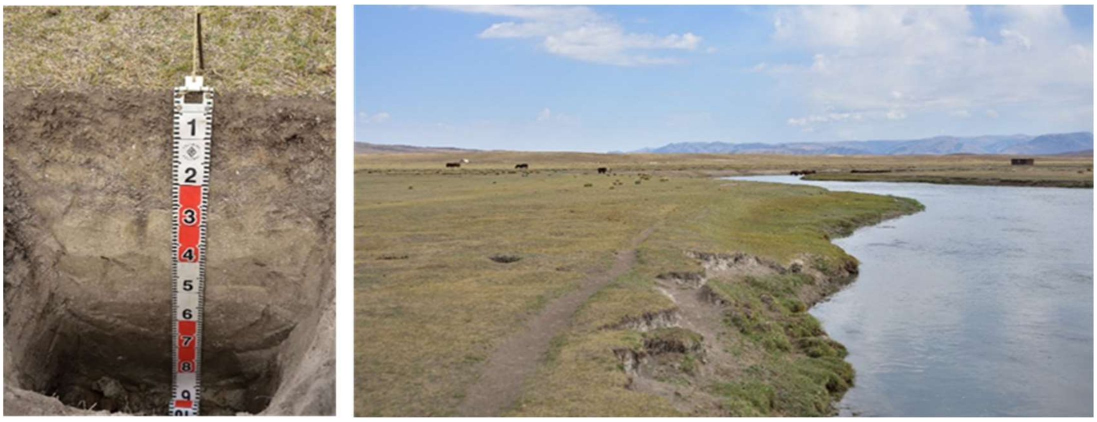

Figure 2. Landscape and soil profile cut 01O of TKS population "Zhalauly".

Soil is characterized by determining the content of humus, total and active forms of macronutrients and micronutrients, availability of exchangeable cations, degree of calcareousness, reaction of soil medium, and other indicators. In the upper horizon, the content of humus is 9.0%, with a depth reduction of up to 0.4% and total nitrogen of 0.4% (Table A1). CO_2 content increases in the carbonate horizon with a depth from 5.0% to 6.4–6.9%. The aggregate of absorbed alkali (Ca, Mg, Na, K) in the upper horizons is 34.26–40.79 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon, but exchangeable Ca^{2+} dominates everywhere (54–84% of the total). The involvement of Mg^{2+} in the absorbing complex is significant (3–36% of the total). Soil solution reaction is alkaline (pH = 8.3–8.6).

The content of easily hydrolyzed nitrogen in the sod horizon is 218.4 mg/kg, with the depth gradually decreasing up to 61.6 mg/kg in the carbonate horizon. The content of mobile phosphorus decreases sharply down the profile from 90 to 3 mg/kg of soil. The content of exchangeable potassium in the upper horizons is 1320–1000 mg/kg, with subsequent decreases up to 280 mg/kg.

The analysis of soil aqueous extract showed that horizons B_1^{CK} and B_C^{CK} presented by alluvial meadowy alkaline medium loam soil (soil profile cut 01O) soil layer within 10–57 cm is strongly saline, salinity type is sulfate by anions, magnesium–calcium by cations. The upper soddy horizon and lower layer of parent rock are not saline (Table A2). The soil texture of soil profile cut 01O is heterogenic. It is a medium loam soil that changes to clay sand and clay loam that transforms into light loam soil (Table A3).

Soil texture has a great influence on soil formation and the agricultural production properties of soils. It affects processes of movement, transformation, and accumulation of substances, as well as the physical, physical–mechanical, and water properties of soil, such as water ratio, water capacity, infiltration of water, water lifting capacity, structural properties, and air and thermal regime. The textural (grading) composition of the soil is determined by the mass content of particles of different grading sizes in it, represented in percentage with respect to the mass of the dry soil sample taken for analysis. It is classified as sandy, sandy loam, light loam, medium loam, clay loam, loamy, or clayed.

Soil profile cut 02O—meadowy alkaline heavy clay loam soil based on saline clay (43°4′14.72″ 79°9′1.86″ H = 1798 m), TKS is absent). The same floodplain terrace is within 200 m of the *T. kok-saghyz* population of "Zhalauly" and is located closer to the mountains (Figure 3). Absinthic and cheegrass vegetation: *Artemisia* [29], *Achnatherum* [32]. Projective cover 50–60%. Height 70–100 cm. Boiling from 7 cm, carbonates in the form of white veins, in a layer of 3-22 cm there is weak boiling. From 65 cm, the boiling of carbonates increases. The depth of the soil profile cut is 90 cm. The humus-accumulated horizon (A + B) = 45 cm.

Figure 3. Landscape and soil profile cut 02O, 200 m from TKS population "Zhalauly".

The upper soddy soil horizon ($A_1{}^s$ = 0–7 cm) is gray, dry, compacted, strongly radiculose, lumpy–dusty, clay loam. The lower soil horizon ($B_1{}^{sk}$ = 7–22 cm) is brownish-gray with numerous salt fibers in freshly compacted, medium loam soil. The carbonate soil horizon ($B_2{}^{sk}$ = 22–45 cm) is brown, fresh, compacted, dusty, lumpy, sandy loam. The horizon (BC = 45–65 cm) is yellowish brown, freshly compacted, indistinctly lumpy, sandy loam. The horizon (C = 65 cm) is grayish-white, poorly moistened, compacted with numerous salt fibers, and sandy loam.

At the upper horizon, the content of humus is 9.2%; with depth, it decreases up to 1.3%, and the total nitrogen is 0.5% (Table A1). The CO_2 content increases with depth from 5.4% to 9.9% in the carbonate horizon. The total volume of absorbed alkali in upper horizons is 33.98–47.99 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon, but exchangeable Ca^{2+} dominates in all horizons (46.3–88.8% of the total). The involvement of Mg^{2+} in the absorbing complex is significant (2.9–41.2% of the total). The soil solution reaction is alkaline (pH = 8.4–8.9).

The content of easily hydrolyzed nitrogen is 243.6 mg/kg in the soddy horizon, with depth gradually decreasing up to 100.8 mg/kg in the carbonate horizon. The content of mobile phosphorus reduces sharply down the profile from 42 to 3 mg/kg of soil. The content of exchangeable potassium in the upper horizons is 1160–1180 mg/kg, with subsequent lowering up to 810 mg/kg.

According to the results of the soil aqueous extract, the upper soddy horizon of meadowy alkaline clay loam soil (soil profile 02O) is moderately saline; the salinity type is sulfate and magnesium–calcium. The lower horizons of the soil, including the parent rock, are highly and very severely salinized; the type of salinization is similar to sulfate and magnesium–calcium saline (Table A2).

The soil texture of 02O is heterogenic. The upper soil horizons consist of clay loam, while the lower horizons are represented by clay sand (Table A3).

Soil profile cut 03O—meadowy alkaline clay loam soil (42°56′14.11″ 79°37′2.67″ H = 1872 m) population of TKS "Saryzhaz". The zone of outcropping of groundwater in the Kegen valley is shown in Figure 4. The vegetation is mixed herbs–sedge: *Carex* [28], *Tragopógon* [33], *Leontopodium* [34], *Caragana* [35], *Elytrigia* [36], and *Rayagarden* [32]. Projective cover 100%. Height from 5 to 7 to 20 to 30 cm. Effervescence from HCl–surface. Salts from 10 to 55 cm of numerous fibers. Depth 100 cm. The humus-accumulated horizon (A + B) = 55 cm.

The upper soddy soil horizon ($A_1{}^s$ = 0–10 cm) is dark gray, dry, compacted, radiculose, granulated, clay loam. The lower soil horizon ($A_2{}^{3C}$ = 10–20 cm) is dark gray, fresh, compacted, radiculose, lumpy–granulated with salt fibers and medium loam. The carbonate soil horizon ($B_1{}^c$ = 20–35 cm) is gray with salt fibers, freshly compacted with sparse roots and clay loam. (B_2 = 35–55 cm) is bluish brownish-light gray, freshly compacted, sharply ribbed granulated, clay loam. Horizon ($C_1{}^{sk}$ = 55–75 cm) is whitish-grayish-brown, freshly compacted, indistinctly lumpy, clay loam. ($C_2{}^{3C}$ = 75–100 cm) bluish-gray with rusty spots, structureless with salt fibers and medium loam.

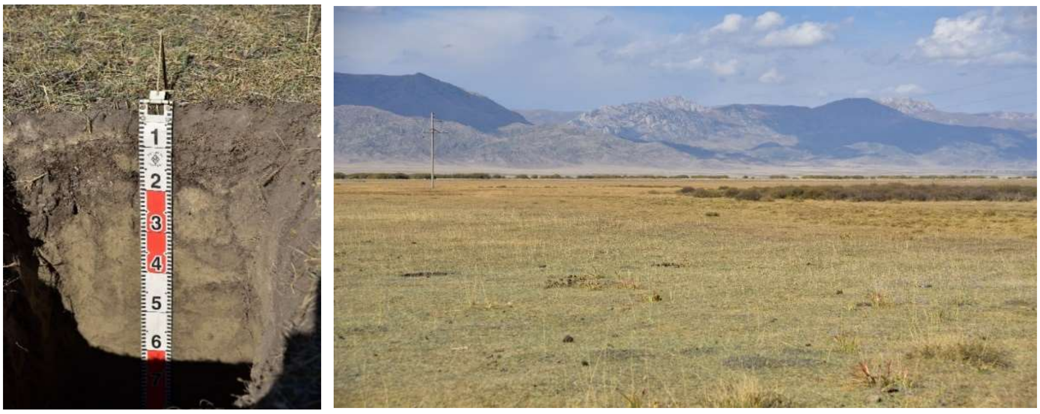

Figure 4. Landscape and soil profile cut 03O of TKS population "Saryzhas".

In the upper horizon, the content of humus is 9.6%; with depth, it decreases up to 2.0%, and total nitrogen is 0.7% (Table A1). The CO_2 content increases with depth from 7.2% up to 7.8–8.7% in the carbonate horizon.

The accumulation of absorbed alkali in the upper horizons is 33.03–51.65 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon but exchangeable Ca^{2+} (57–82% of the total). The involvement of Mg^{2+} in the absorbing complex is significant (7–36% of the total). The soil solution reaction is strongly alkaline (pH = 8.6–9.0).

The content of easily hydrolyzed nitrogen is 148.4 mg/kg in the soddy horizon, with depth gradually decreasing by up to 75.6 mg/kg in the carbonate horizon. The content of mobile phosphorus decreases sharply down the profile from 44 to 5 mg/kg of soil. The content of exchangeable potassium in the upper horizon is 720 mg/kg, with subsequent reductions up to 140 mg/kg.

Analysis of soil aqueous extraction data showed that lower horizons A_2 and B_1 of the meadowy alkaline clay loam soil (soil profile 03O) are strongly and moderately saline, and the salinity type is sulfate, magnesium–calcium, and sulfate–sodium (Table A2). The lower soil horizons up to the parent rock are not saline. The soil texture of 03O is heterogenic. The succession of clay loam and medium loam is observed by horizon (Table A3).

Soil profile cut 04O—meadowy alkaline medium loam soil based on loams (42°55′54.11″ 79°36′59.89″ H = 1888 m), and TKS is absent. The same zone of groundwater wedging is 100 m higher from the population of *T. kok-saghyz* "Saryzaz" to the mountains (Figure 5). Vegetation: *Artemisia* [29], *Phragmítes australis* [37], *Elytrigia* [36], *Camphorosmeae* [38], *Achnatherum* [32], and *Puccinéllia* [39]. Projective cover 100%. Height 5–15 cm (at which cattle eat). Cheegrass up to 1 m. Depth 70 cm. The humus-accumulated horizon (A + B) = 50 cm. Effervescence from HCl–surface. Salts are not visible.

The upper soddy horizon ($A_1{}^s$ = 0–10 cm) is dark gray, freshly compacted, highly stubby, medium loam, and lumpy. The lower horizon (AB = 10–25 cm) is grayish-dark brown, slightly compacted, dusty and lumpy, medium loam. The horizon (B_1 = 25–50 cm) is brown, freshly compacted, and lumpy with dusty clay loam. The horizon (C_1 = 50 cm) is yellow-brown, freshly compacted, clumpy, clay loam.

In the upper horizon, the content of humus is 9.5%; with depth, it decreases up to 1.6%, and total nitrogen is 0.7% (Table A1). The CO_2 content increases with the depth from 3.2% to 12% in the carbonate horizon. The accumulation of absorbed alkali in the upper soil horizons ranges from 30.37 to 44.52 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon, but exchangeable Ca^{2+} dominates in all horizons (29–66% of the total). The involvement of Mg^{2+} in the absorbing complex is significant (25–45% of the total). The soil solution reaction is strongly alkaline (pH = 8.3–9.2).

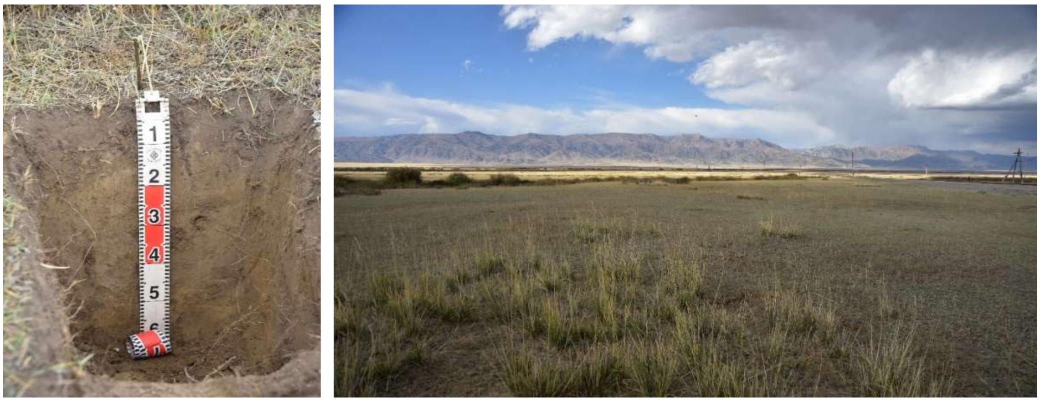

Figure 5. Landscape and soil profile cut 04O, 100 m from TKS population "Saryzhas".

The content of easily hydrolyzed nitrogen is 201.6 mg/kg in the soddy horizon; with depth, it gradually reduces up to 144.0 mg/kg in the carbonate horizon. The content of mobile phosphorus drastically declines down the profile from 52 up to 3 mg/kg of soil. The content of exchangeable potassium in the upper horizons is 1660–1400 mg/kg, with subsequent lowering up to 1320 mg/kg.

Determination of soil aqueous extract allowed for determining the degree and chemical properties of salinization. The analysis showed that the whole profile of meadowy alkaline medium loam soil (soil profile 04) is very intensive and severely salinized by chloride–sulfate anions and by calcium–magnesium, magnesium–sodium, and sodium cations (Table A2). The soil texture is heterogenic. It is observed that there are alternating horizons of medium loam and clay loam (Table A3).

Soil profile cut 05O—floodplain meadowy alkaline clay loam soil (43°1′19.15″ 79°14′21.89″ H = 1810 m) TKS "Kegen" population. The floodplain of the Kegen River. The soil profile above the cliff face is shown in Figure 6. The water edge is 1 m 60 cm. The vegetation is cattle-beaten; mixed herbs–sedge vegetation: *Carex* [28], *Taraxacum* [31], and *Fenugreek* [40]. Effervescence from HCl–surface. Salts in the profile from 10 to 67 cm are scarce; from 67 cm, they are abundant. Projective cover 100%. Height 2–3 cm. Depth 90 cm. The humus-accumulated horizon (A + B) = 35 cm.

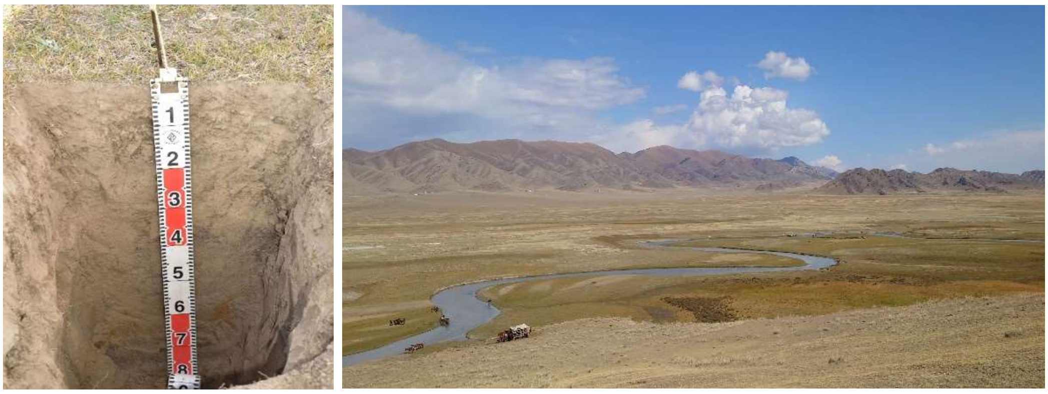

Figure 6. Landscape and soil profile cut 05O of TKS population "Kegen".

The upper soddy horizon ($A_1{}^s$ = 0–7 cm) is brownish-darkish-gray, dry, compacted, strongly radiculose, dusty-granulated, light loam. (AB = 7–18 cm) is brownish-gray, dry, compacted, radiculose, lumpy, clay loam. The carbonate horizon (B_1 = 18–35 cm) is brown, grayish, fresh, dense, clay loam. The transitional horizon (BC = 35–55 cm) is brown, fresh, compacted, granular, clay loam. Horizon (C_1 = 55–70 cm) is rusty-brown, fresh, compacted, indistinctly clayey clays. ($C_2{}^{3C}$ = 70–100 cm) is dirty brown, fresh, compacted, clay loam.

In the upper horizon, the content of humus is 4.2%; with depth, it decreases up to 0.8%, and total nitrogen is 0.4% (Table A1). The CO_2 content increases with depth from 6.6% to 11.5% in the carbonate horizon. The accumulation of absorbed alkali in the upper soil horizons is 22.88–25.66 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon, but exchangeable Ca^{2+} dominates in all horizons (27–63% of the total). The involvement of Mg^{2+} in the absorbing complex is significant (22–65% of the total). The soil solution reaction is alkaline (pH = 9.1–9.3).

According to the results of the aqueous extract, it was proved that the soddy horizon of floodplain meadowy alkaline clay loam soil (soil profile 05O) is not saline. While gradually increasing and then declining, soil salinity is observed down the soil profile up to 50 cm. Severely saline horizon AB is replaced by moderately saline horizon (B_1). The transitional horizon (BC) is slightly saline (Table A2). Chloride–sulfate and sodium types of salinization are observed. Nevertheless, the lower horizon of the parent rock is not saline and is not the source of origin of soil profile salinization. Soil texture is heterogenic. There is an interchanging of light and medium loam on horizons, then transition to sandy loam (Table A3).

Soil profile cut 08O meadowy xeromorphic alkaline medium loam based on gravel (43°1′26.56″ 79°14′30.53″ H = 1823 m), and TKS is absent. The terrace of the Kegen River is up 150 m above the soil profile of the TKS "Saryzhaz" population on the floodplain (Figure 7). The vegetation includes *Achnatherum* [32] and *Carex* [28]. Depth 50 cm. The humus-accumulated horizon (A + B) = 40 cm. Effervescence from HCl–surface. Salts—none are visible.

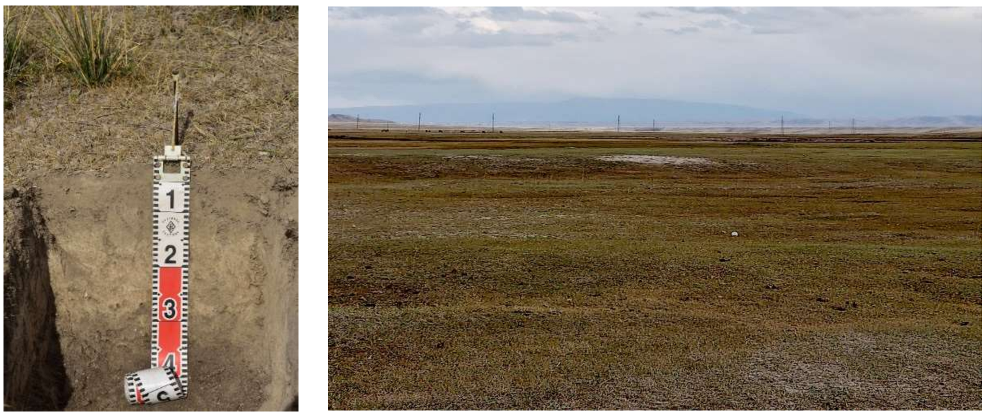

Figure 7. Landscape and soil profile cut 08O, 150 m from TKS population "Kegen".

The upper soddy horizon (A_1^s = 0–5 cm) is gray, dry, dusty, radiculose, medium loam, and dusty–lumpy. (AB = 5–15 cm) is gray, dry, compacted, radiculose, lumpy–powdery, clay l (B_1 = 15–30 cm) light gray, dry, dusty-platy, clay loam. Horizon (B^1 = 30–40 is dark gray, dry, dense, gruffly lumpy, clay loam. Horizon (CD = 40–50 cm) is gravel with a moderate quantity of fine earth.

In the upper horizon, the content of humus is 5.5%; with depth, it decreases up to 0.8%, and total nitrogen is 0.4% (Table A1). The CO_2 content is increased with depth from 6.7% to 11.1% in the carbonate horizon. The accumulation of absorbed alkali in the upper soil horizons is 20.95–31.13 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon, but exchangeable Ca^{2+} dominates in all horizons (10–73% of the total). The involvement of Mg^{2+} in the absorbing complex is significant (21–75% of the total). The soil solution reaction is extremely strong alkaline (pH = 10.2–10.3).

The content of easily hydrolyzed nitrogen is 126.0 mg/kg in the soddy horizon; with depth, it gradually declines up to 52.7 mg/kg in the carbonate horizon. The content of mobile phosphorus sharply reduced the profile from 70 to 3 mg/kg of soil. The content of exchangeable potassium in the upper horizons is 1000–950 mg/kg, with subsequent decreases up to 770 mg/kg.

The whole profile of meadowy xeromorphic alkaline medium loam soil is saline. Therefore, the soddy horizon is slightly saline (Table A2). The soil salinization increased to a very severe level, which was observed in the AB and B_1 horizons. In lower soil horizons, the soil is highly saline. The soil salinization type is chloride–sulfate and sodium. Soil texture is heterogenic. The soddy horizon is represented by light loam. The whole lower profile is clay loam (Table A3).

Morphogenetic Features and Physicochemical Properties of the Studied Soils near the "Tuzkol" Salt Lake.

Soil profile cut 06O TKS "Tuzkol" population. Meadowy alkaline clay loam soil based on sand (43°1′34.77″ 79°59′17.30″ H = 1962 m). Shore of Tuzkol Lake (Figure 8). Along the lake, a strip of alkaline soils above sedge vegetation with meadowy plantain (*Plantago* L.). Cut on the low side of the lake 30 m from the water. Vegetation: *Carex* [28], *Plantago salsa* [41], *Fenugreek* [40], and *Taraxacum* [31]. Projective cover 100%. Height 2–3 cm. Effervescence from HCl–surface. Salts 40–60 cm sparse fibers. Depth 90 cm. The humus-accumulated horizon (A + B) = 15 cm.

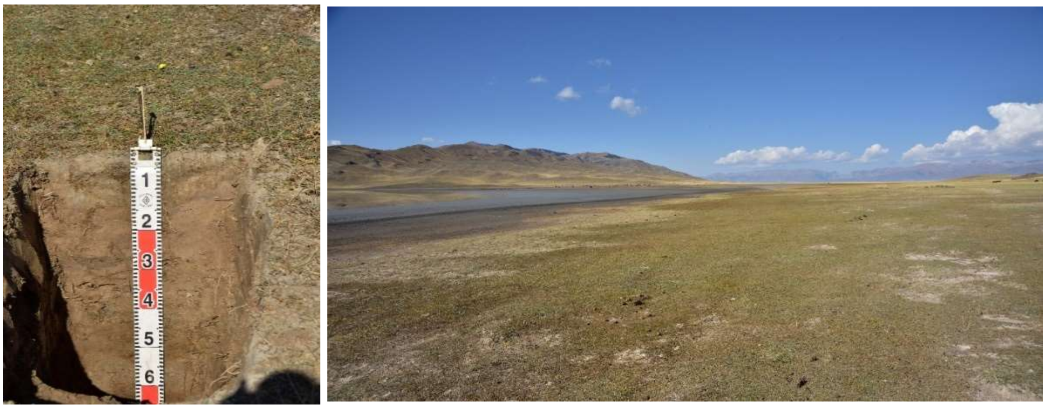

Figure 8. Landscape and soil profile cut 06O of TKS population "Tuzkol".

The upper soddy horizon (A = 0–5 cm) is light grayish with rusty spots, freshly compacted, clay loam, and heavily lumpy. The lower soil horizon (B_1 = 5–15 cm) is brown with rusty spots and is freshly compacted, lumpy clay loam. The horizon (C_1 = 15–40 cm) is yellowish-brown, slightly humid, compacted, structureless, and clayey. (C_2 = 40–60 cm) is light-grained, humid, slightly compacted, indistinctly clumpy loamy sandy loam. (C_3 = 60–84 cm) is dark brown, humid, poorly compacted, fine-graded sand.

In the upper horizon, the content of humus is 2.8%; with depth, it decreases up to 1.1%, and total nitrogen is 0.2% (Table A1). The CO_2 content decreases with depth from 9.8% to 9.0% in the carbonate horizon.

The accumulation of absorbed alkali in the upper layer is 22.83 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon, but exchangeable Ca^{2+} dominates in all horizons (74–82% of the total).

The involvement of Mg^{2+} in the absorbing complex is insignificant (11–15% of the total). The soil solution reaction is strongly alkaline (pH = 8.5–9.3).

The content of easily hydrolyzable nitrogen is 148.4 mg/kg in the upper horizon; with depth, it decreases up to 70 mg/kg in the carbonate horizon. The content of mobile phosphorus sharply decreases across the profile from 34 to 8 mg/kg of soil. The content of exchangeable potassium in the upper horizon is 220 mg/kg, with subsequent decreases up to 130 mg/kg. Analysis of aqueous extract data showed that the reduction of salinization is observed further down the profile of meadowy heavy loamy soil (soil profile 06O) starting from a soddy, strongly saline horizon (Table A2).

The medium-saline horizon B_1 is substituted by weakly saline horizon C_1. Cy Sulfate–magnesium–sodium type of salinization is replaced by chloride–sulfate–sodium type. In the lower horizons of the parent rocks C_2 and C_3, salinization is not observed. The soil texture of soil profile cut 06O is heterogenic.

In the upper and lower horizons, the soil texture is sandy clay, and the middle horizon is light loam soil (Table A3).

Soil profile cut 07O—meadowy alkaline medium loam based on loam soil (43°1′35.58″ 79°59′17.35″ H = 1963 m), and TKS is absent. It is 30 m from the *T. kok-saghyz* population "Tuzkol" (Figure 9). Vegetation cheegrass—shrenkovaya and absinthic: *Artemisia* [29], *Lasiagrostis* [32], *Achnatherum* [32], *Plantago salsa* [41], and *Festúca valesiáca* [42]. Depth 90 cm. The humus-accumulated horizon (A + B) = 23 cm. Effervescence from HCl–surface. Salts are not visible. Carbonates from 50 cm. Projective cover 100%. Height 10–15 cm. Upper soddy horizon (A_1 = 0–6 cm) is dark grayish, dry, strongly compacted, radiculose, imperfectly lumpy, dusty, sandy loam.

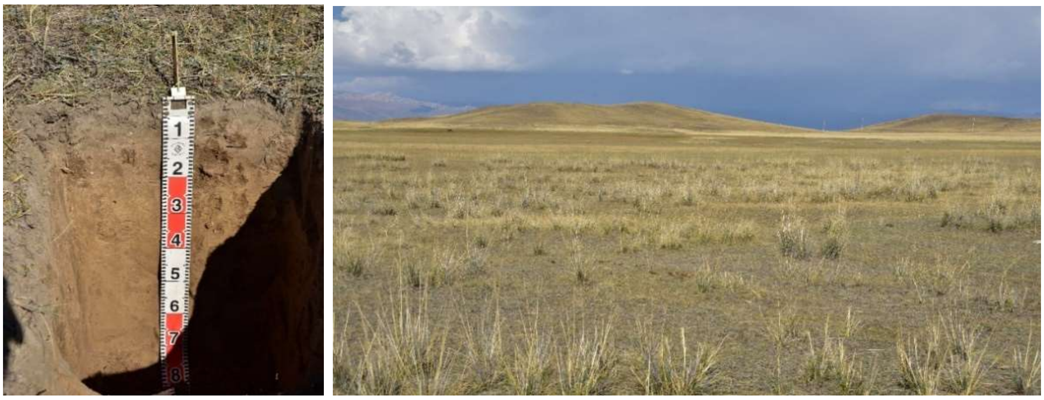

Figure 9. Landscape and soil profile cut 07O, 30 m from TKS population "Tuzkol".

The lower soil horizon (B_1 = 6–23 cm) is dark brown, freshly compacted, with roots that are not firmly clumped sandy loam. Transitional horizon (BC = 23–40 cm) is brown, fresh, compacted, indistinctly lumpy, medium loam. (C_1 = 40–60 cm) is brown, fresh, compacted, dusty and lumpy, light loam. (C_2 = 80–90 cm) is similar to the previous one, but with humid soil.

In the upper horizon, the content of humus is 4.0% with depth and decreases up to 0.1%, and total nitrogen is 0.4%. (Table A1). The CO_2 content increases with depth from 3.7 to 7.8–8.3% in the carbonate horizon. The accumulation of absorbed alkali in the upper horizons is 12.91–16.57 mg-eq. per 100 g of soil. The quantitative composition of absorbed alkali varies widely by horizon, but in each horizon, exchangeable calcium dominates (9–80% of the total). The involvement of Mg^{2+} in the absorbing complex is not substantial (15% of the total). The reaction of the soil solution is very strongly alkaline (pH = 9.3–10.2).

The content of easily hydrolyzed nitrogen in the soddy horizon is 109.2 mg/kg; with depth, it is gradually reduced up to 47.6 mg/kg in the carbonate horizon. The content of mobile phosphorus sharply decreases further down the profile from 37 to 10 mg/kg of soil. The content of exchangeable potassium in the upper horizons is 1000–1180 mg/kg, with subsequent decline up to 870 mg/kg.

The whole profile of meadowy alkaline medium loam soil is salinized to different extents. So, a low saline soddy horizon is replaced by a highly saline middle profile (B_1, BC и C_1) (Table A2). The lower layer of the parent rock C_2 is moderately saline. Soil texture is heterogenic. The soddy and lower horizons are represented by loamy sand. Down the soil profile, it is observed to be an interchange of middle loam and light loam (Table A3).

4. Discussion

The soils of the studied TKS populations and remote areas where TKS is not present have the following general characteristics—meadowy soils with well-developed humus horizons are often saline and carbonate. The type of soil profile is regular and has a full set of horizons and usual soil depth. In soils of TKS populations on the shore of the Kegen River and remote areas where TKS is absent, humus content reduces from 9.0% to 0.4% with the depth of soil profile cut in the "Zhalauly" population, easily hydrolyzable nitrogen drops from 218.4% to 61.6%, and mobile phosphorus reduces from 90% to 3%.

The content of CO_2 increases with depth, for example, in the "Kegen" population from 6.6% to 11.5% in the carbonate horizon. The quantitative composition of absorbed alkali varies widely by horizon, but exchangeable Ca^{2+} dominates in all horizons. The involvement of Mg^{2+} in the absorbing complex is significant (21–75% of the total). The soil solution reaction is strongly alkaline (pH 8.3–10.3). However, the exception is the soil profile features of the TKS population "Tuzkol"—CO_2 content does not increase but decreases with the depth of the soil profile cut.

The soils of *T. kok-saghyz* in situ populations contained increased CO_2 content. The more elevated above sea level the kok-saghyz population, the higher the CO_2 content in the soil. The lowest elevation point, 1798 m above sea level soil of "Zhalauly" population, contains 5% CO_2; then the elevation point above 1810 m soil of "Kegen" population has 6.6% CO_2; the next elevation point above 1872 m soil of "Saryzhaz" population has 7.2% CO_2; and the highest elevation point 1962 m above sea level soil of "Tuzkol" population has 29.8% CO_2.

It has been reported that the CO_2 content in soil used for the cultivation of agricultural crops does not exceed 1%. Changes in concentrations of CO_2 and O_2 are interrelated across the soil profile. The maximum content of CO_2 corresponds to the minimum concentration of oxygen. The total of these gases in soil air is 21%. The optimal content of O_2 and CO_2 in soil air is, respectively, 20% and 1% [43].

Based on the soil texture of TKS in situ populations identified medium loam soil ("Zhalauly"), clay loam soil and medium loam soil ("Saryzhaz"), and clay loam soil ("Kegen", "Tuzkol"). It is apparent that high clay content in the soil reduces air-holding capacity and is the cause of oxygen shortage [44]. Conclusively, the results suggest soil hypoxia (oxygen deficiency) in the TKS in situ populations.

Soil horizons of TKS in situ populations and soils of the remote areas where TKS is absent have features of soil profile salinization. In the near-shore zone of the Kegen River, the upper horizons of in situ TKS populations of "Zhalauly", "Kegen", and "Saryzhaz" study areas are slightly saline, and the middle soil horizons are saline. The lower horizons of the parent rock at a depth of 90–100 cm are not saline (salt content is less than 0.1%) and do not cause salinization of the soil profile.

Nevertheless, the upper horizon and the whole profile of soil horizons remote from TKS populations "Zhalauly", "Kegen", and "Saryzhaz", where TKS is not observed, are saline, and the lower horizon of the parent rock is highly saline.

The only exception is the profile of soil horizons of the "Tuzkol" population; the upper horizon up to 15 cm depth is strongly saline (1.38%), then there is a decrease in salinity throughout the profile. In the lower horizon of the parent rock (90 cm deep), salinization is not observed (0.045%). Probably, specific features of salinization of the "Tuzkol" in situ soil profile population are caused by the inflow of non-saline water from underground streams and spring wells.

Soil alkalinity, which means soils with increased content of exchangeable sodium along with water supply, also limits the distribution of TKS in the natural growth area. It was revealed that TKS is not found on alkaline soils remote from the populations of "Kegen", "Zhalauly", and "Tuzkol". It is known that an especially negative impact on plants comes from sodium ions; when penetrating into cells, sodium disrupts the balance between sodium and potassium, calcium and potassium, and worsens the absorption of macronutrients and micronutrients, resulting in the inhibition of the activity of many enzymes, thus repressing protein synthesis [45].

The analysis of edaphoclimatic conditions of natural habitats of TKS indicates a sharply distinct continental character of the climate. The instability of meteorological parameters and the onset of drought in the second half of summer are typical features. During the summer period, the average temperature was recorded at +13.2 °C (June), +16.5 °C (July), and +15.7 °C (August). The amount of precipitation is at its maximum in June, which is 64.5 mm. The lowest ambient air temperatures are recorded in January, December, and February, down up to −7.9 °C during the day and up to −20.1 °C at night. The snow cover is solid and is in place in the first half of November. Spring snowmelt begins at the end of March [46].

In conclusion, the main factor limiting the spread of TKS in the zone of its natural habitats is not the degree of salinization of the upper horizons of soil profiles but sufficient water supply. TKS vegetates on the shores of the Kegen River and Tuzkol Lake, namely, closer to water.

5. Conclusions

TKS is a facultative halophyte, i.e., it develops well both on strongly saline and slightly saline soils under in situ conditions and under ex situ conditions in non-saline soils.

Soils in the in situ growth zone of TKS and soils remote from its populations (100–200 m) have common characteristics:

(a) High humus content (consequently fertility);
(b) Soil hypoxia;
(c) Low, medium, and strong degrees of saline soil with a high carbonate content.

TKS is a facultative halophyte, i.e., it develops well both on highly saline and low-saline soils under in situ conditions and under ex situ conditions in non-saline soils.

The main factor that limits the spread of TKS in its in situ zone is a sufficient water supply (hydrogenity) for the soil. TKS grows on the banks of the Kegen River and Lake Tuzkol, in particular, closer to the water.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Physical and chemical properties of soils.

No. Soil Profile Cut	Depth, cm	Humus, %	Total Nitrogen, %	CO_2, %	Exchange Cations, mg-eq./100 g				pH Hydric	Active Forms, mg/kg		
					Ca	Mg	Na	K		P_2O_5	K_2O	N
01O	0–10	9.0	0.4	5.0	28.7	1.0	2.5	2.1	8.6	90	1320	218.4
	13–23	2.1	0.3	6.9	22.3	14.9	2.4	1.2	8.6	3	1000	170.8
	38–48	0.4	0.1	6.4	17.3	9.9	0.7	0.1	8.3	3	280	61.6

Table A1. *Cont.*

No. Soil Profile Cut	Depth, cm	Humus, %	Total Nitrogen, %	CO_2, %	Exchange Cations, mg-eq./100 g				pH Hydric	Active Forms, mg/kg		
					Ca	Mg	Na	K		P_2O_5	K_2O	N
02O	0–7	9.2	0.5	5.4	30.2	1.0	1.7	1.1	8.4	42	1180	243.6
	10–20	8.1	0.5	3.9	24.8	19.8	2.2	1.2	8.5	10	1160	232.4
	27–37	1.3	0.1	9.9	17.8	14.9	5.0	0.7	8.9	3	810	100.8
03O	0–10	9.6	0.7	7.2	27.2	2.5	2.6	0.7	8.8	44	720	148.4
	10–20	9.1	0.7	6.7	29.7	18.8	3.0	0.2	8.6	29	310	206.5
	22–32	6.0	0.4	8.7	26.2	3.5	2.3	0.2	8.7	10	200	159.6
	40–50	2.0	0.2	7.8	16.3	8.4	3.2	0.2	9.0	5	140	75.6
04O	0–10	9.5	0.7	3.2	29.7	11.4	1.7	1.7	8.3	52	1660	201.6
	12–22	2.5	0.2	9.8	17.3	12.4	5.0	1.4	8.9	5	1400	199.5
	32–42	1.6	0.1	12.0	8.9	13.9	5.9	1.7	9.2	3	1320	144
05O	0–7	4.2	0.4	6.6	6.4	14.9	1.0	0.6	9.1	44	1180	131.6
	8–18	3.2	0.3	7.8	16.3	5.9	3.1	0.3	9.3	18	380	159.6
	21–31	1.0	0.1	8.8	8.9	8.4	1.7	0.2	9.3	8	140	89.6
	40–50	0.8	0.1	11.5	8.9	5.9	2.1	0.2	9.2	3	80	59.5
06O	0–5	2.8	0.2	9.8	18.8	3.5	0.5	0.1	8.5	34	220	148.4
	5–15	1.1	0.1	9.0	6.4	1.0	0.9	0.2	9.3	8	130	70
07O	0–6	4.0	0.4	3.7	10.4	2.0	0.2	0.4	9.3	37	1000	109.2
	10–20	2.0	0.2	8.3	1.5	2.5	11.7	0.9	10.2	20	1180	117.6
	27–37	0.1	0.2	7.8	1.5	3.5	2.3	0.4	10.2	10	870	47.6
08O	0–5	5.5	0.4	6.7	15.4	4.5	0.8	0.3	8.8	70	1000	126
	5–15	1.7	0.2	10.7	4.0	8.9	17.6	0.7	10.3	15	950	134.4
	17–27	0.7	0.1	10.0	3.5	7.4	2.1	0.5	10.2	5	770	75.6
	30–40	0.8	0.1	11.1	1.5	10.9	1.6	0.4	10.2	3	810	52.7

Table A2. Water-soluble salt composition, %/mg-eq.

No. Soil Profile Cut	Sample Depth, cm	Salt Amount	Alkalinity		Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
			Total in HCO_3^-	From Standard Carbonates in CO_3^{2-}						
1	2	3	4	5	6	7	8	9	10	11
01O	0–10	0.194	0.068	0	0.014	0.049	0.008	0.005	0.027	0.022
			1.12	0	0.41	1.02	0.4	0.39	1.18	0.57
	13–23	2.02	0.032	0	0.109	1.288	0.27	0.097	0.179	0.044
			0.52	0	3.07	26.84	13.5	8.0	7.79	1.14
	38–48	1.368	0.017	0	0.028	0.928	0.325	0.033	0.025	0.012
			0.28	0	0.78	19.34	16.25	2.75	1.09	0.3
	65–75	0.098	0.027	0	0.003	0.042	0.01	0.006	0.008	0.002
			0.44	0	0.07	0.88	0.5	0.49	0.34	0.06

Table A2. *Cont.*

No. Soil Profile Cut	Sample Depth, cm	Salt Amount	Alkalinity		Cl⁻	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
			Total in HCO_3^-	From Standard Carbonates in CO_3^{2-}						
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
02O	0–7	0.883	0.032	0	0.016	0.57	0.15	0.022	0.066	0.028
			0.52	0	0.44	11.89	7.5	1.78	2.85	0.72
	10–20	2.097	0.029	0	0.153	1.287	0.285	0.082	0.222	0.038
			0.48	0	4.32	26.82	14.25	6.75	9.64	0.98
	27–37	2.435	0.02	0	0.202	1.497	0.275	0.122	0.293	0.028
			0.32	0	5.69	31.18	13.75	10	12.73	0.71
	50–60	2.075	0.015	0	0.152	1.295	0.27	0.088	0.236	0.019
			0.24	0	4.29	26.98	13.5	7.25	10.26	0.49
	80–90	1.671	0.012	0	0.081	1.071	0.36	0.015	0.122	0.009
			0.2	0	2.29	22.32	18	1.25	5.32	0.24
03O	0–10	0.247	0.076	0.005	0.01	0.093	0.014	0.014	0.033	0.007
			1.24	0.16	0.3	1.94	0.7	1.18	1.41	0.17
	10–20	1.343	0.054	0	0.035	0.85	0.2	0.02	0.179	0.004
			0.88	0	1	17.7	10	1.68	7.79	0.11
	22–32	0.788	0.051	0	0.03	0.466	0.044	0.017	0.179	0.001
			0.84	0	0.85	9.71	2.2	1.38	7.79	0.03
	40–50	0.303	0.056	0.005	0.013	0.147	0.004	0.016	0.066	0.001
			0.92	0.16	0.37	3.07	0.2	1.28	2.85	0.03
	60–70	0.118	0.039	0	0.005	0.041	0.006	0.005	0.021	0.001
			0.64	0	0.15	0.85	0.3	0.39	0.91	0.03
04O	0–10	1.045	0.044	0	0.1	0.567	0.078	0.03	0.179	0.047
			0.72	0	2.81	11.82	3.9	2.47	7.79	1.19
	12–22	2.11	0.039	0.005	0.182	1.243	0.176	0.09	0.321	0.059
			0.64	0.16	5.13	25.9	8.8	7.4	13.97	1.51
	32–42	1.006	0.049	0.007	0.172	0.451	0.014	0.025	0.264	0.03
			0.8	0.24	4.84	9.4	0.7	2.07	11.49	0.78
	60–70	0.983	0.034	0.005	0.159	0.471	0.01	0.035	0.25	0.024
			0.56	0.16	4.47	9.82	0.5	2.86	10.88	0.61
05O	0–7	0.132	0.059	0.002	0.004	0.032	0.004	0.005	0.023	0.006
			0.96	0.08	0.11	0.67	0.2	0.39	0.98	0.16
	8–18	0.81	0.073	0.007	0.113	0.36	0.01	0.012	0.236	0.005
			1.2	0.24	3.18	7.51	0.5	0.99	10.26	0.14
	21–31	0.598	0.063	0.007	0.079	0.262	0.008	0.006	0.179	0.001
			1.04	0.24	2.22	5.45	0.4	0.49	7.79	0.02
	40–50	0.373	0.059	0.002	0.037	0.16	0.004	0.005	0.108	0.001
			0.96	0.08	1.03	3.32	0.2	0.39	4.7	0.02
	57–67	0.136	0.061	0.005	0.009	0.026	0.002	0.002	0.034	0.001
			1	0.16	0.26	0.55	0.1	0.2	1.49	0.02

Table A2. *Cont.*

No. Soil Profile Cut	Sample Depth, cm	Salt Amount	Alkalinity: Total in HCO_3^-	Alkalinity: From Standard Carbonates in CO_3^{2-}	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
1	2	3	4	5	6	7	8	9	10	11
06O	0–5	1.38	0.041	0	0.063	0.845	0.16	0.012	0.25	0.008
			0.68	0	1.77	17.61	8	0.99	10.88	0.2
	5–15	0.629	0.088	0.007	0.075	0.263	0.004	0.005	0.193	0.001
			1.44	0.24	2.11	5.48	0.2	0.39	8.41	0.02
	22–32	0.35	0.061	0.007	0.031	0.146	0.002	0.001	0.108	0.001
			1	0.24	0.89	3.04	0.1	0.1	4.7	0.02
	45–55	0.12	0.022	0	0.012	0.052	0.01	0.006	0.018	0.001
			0.36	0	0.33	1.09	0.5	0.49	0.76	0.02
07O	0–6	0.377	0.078	0.007	0.047	0.13	0.002	0.004	0.108	0.008
			1.28	0.24	1.33	2.7	0.1	0.3	4.7	0.21
	10–20	1.063	0.229	0.067	0.156	0.33	0.002	0.006	0.321	0.018
			3.76	2.24	4.4	6.87	0.1	0.49	13.97	0.47
	27–37	0.87	0.166	0.017	0.119	0.299	0.004	0.001	0.27	0.011
			2.72	0.56	3.36	6.23	0.2	0.1	11.73	0.28
	45–55	0.704	0.134	0.01	0.079	0.263	0.002	0.001	0.22	0.006
			2.2	0.32	2.22	5.48	0.1	0.1	9.55	0.15
08O	0–5	0.317	0.049	0	0.029	0.137	0.006	0.005	0.08	0.012
			0.8	0	0.81	2.86	0.3	0.39	3.47	0.31
	5–15	1.182	0.346	0.067	0.09	0.383	0.01	0.017	0.321	0.014
			5.68	2.24	2.55	7.98	0.5	1.38	13.97	0.36
	17–27	0.832	0.222	0.041	0.059	0.294	0.004	0.01	0.236	0.007
			3.64	1.36	1.66	6.13	0.2	0.79	10.26	0.18
	30–40	0.919	0.276	0.046	0.056	0.31	0.002	0.017	0.25	0.008
			4.52	1.52	1.59	6.45	0.1	1.38	10.88	0.2

Table A3. Soil texture.

No. Soil Profile Cut	Sample Depth, cm	A.C.H % H_2O	Fractional Content in % per Absolute Dry Soil — Fraction Size in mm: Sand 1.0–0.25	Sand 0.25–0.05	Dust 0.05–0.01	Dust 0.01–0.005	Dust 0.005–0.001	Silty Mud < 0.001	∑ Three FRACTIONS <0.001: (0.01–0.005, 0.005–0.001, <0.001)
01O	0–10	4.56	10.792	17.540	39.816	5.448	21.375	5.029	31.852
	13–23	2.76	18.223	21.719	27.561	12.752	18.100	1.645	32.497
	38–48	1.68	15.338	15.907	50.448	6.509	10.171	1.627	18.308
	65–75	2.44	16.646	15.703	20.090	11.070	24.190	12.300	47.560
	90–100	1.26	13.996	29.289	31.193	0.810	8.507	16.204	25.522
02O	0–7	4.06	3.877	9.819	35.856	37.940	11.257	1.251	50.448
	10–20	4.04	6.315	14.485	39.183	22.926	9.170	7.920	40.017
	27–37	4.30	20.042	3.051	60.606	2.508	9.195	4.598	16.301
	50–60	3.72	29.248	2.617	48.193	5.816	9.140	4.985	19.942
	80–90	1.90	17.757	10.479	58.308	3.262	5.708	4.485	13.456

Table A3. *Cont.*

No. Soil Profile Cut	Sample Depth, cm	A.C.H % H_2O	Fractional Content in % per Absolute Dry Soil						
			Fraction Size in mm						
			Sand		Dust			Silty Mud < 0.001	∑ Three FRACTIONS <0.001: (0.01–0.005, 0.005–0.001, <0.001)
			1.0–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001		
03O	0–10	5.92	9.715	8.652	33.163	17.857	24.660	5.952	48.469
	10–20	6.22	11.666	11.559	38.388	15.355	12.796	10.237	38.388
	22–32	3.56	11.717	3.256	28.204	17.005	30.278	9.540	56.823
	40–50	2.70	11.326	2.343	36.177	19.733	27.955	2.467	50.154
	60–70	2.70	21.151	2.384	20.144	15.622	26.310	14.388	56.321
	90–100	2.40	42.193	2.070	14.754	7.787	31.557	1.639	40.984
04O	0–10	4.88	14.361	8.684	39.950	16.400	13.877	6.728	37.006
	12–22	4.48	2.178	1.089	58.208	0.838	34.338	3.350	38.526
	32–42	4.32	28.658	1.108	16.304	6.271	22.157	25.502	53.930
	60–70	3.40	26.791	3.230	26.087	26.087	2.484	15.321	43.892
05O	0–7	3.10	29.825	6.192	42.931	0.826	14.861	5.366	21.053
	8–18	3.44	39.002	3.003	30.240	3.728	22.784	1.243	27.755
	21–31	3.22	24.695	1.736	37.198	4.546	22.319	9.506	36.371
	40–50	2.44	25.359	1.251	41.000	6.560	11.890	13.940	32.390
	57–67	1.88	51.203	12.923	14.268	0.815	12.638	8.153	21.606
	80–90	1.14	62.371	8.092	15.375	7.283	1.618	5.260	14.161
06O	0–5	2.44	27.101	35.998	20.090	2.460	10.250	4.100	16.810
	5–15	1.94	29.247	33.225	22.027	0.408	8.566	6.527	15.501
	22–32	1.54	50.091	12.127	14.219	1.219	10.563	11.781	23.563
	45–55	1.52	38.444	13.627	28.026	2.843	9.748	7.311	19.903
	80–90	1.22	39.461	44.746	3.644	3.644	4.454	4.049	12.148
07O	0–6	2.68	14.755	12.084	54.665	3.699	4.932	9.864	18.496
	10–20	2.36	21.221	6.268	54.486	6.145	4.097	7.784	18.025
	27–37	1.46	31.703	5.784	23.950	4.465	18.267	15.831	38.563
	45–55	1.08	40.700	13.607	17.388	2.022	12.940	13.344	28.306
	80–90	1.02	39.523	26.126	12.932	4.041	8.082	9.295	21.418
08O	0–5	2.64	19.063	29.992	26.294	7.395	9.449	7.806	24.651
	5–15	2.12	7.397	9.236	26.154	8.991	33.102	15.121	57.213
	17–27	2.22	12.722	10.370	20.045	8.591	26.590	21.681	56.862
	30–40	2.98	10.534	9.895	20.614	9.070	31.334	18.553	58.957
	40–50	7.40	6.436	14.514	21.166	5.616	30.670	21.598	57.883

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