RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (2) 761-771, 2025
http://doi.org/10.54910/sabrao2025.57.2.32
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

MINERALOGICAL STUDIES OF THE IRRIGATED AND NON-IRRIGATED SIEROZEM SOILS IN TURKESTAN REGION, KAZAKHSTAN

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SUMMARY

The research presents mineralogical studies of irrigated and non-irrigated sierozem soils of the Shaulder irrigation massif of Turkestan Region, Kazakhstan. Soils and soil cover representations comprised zonal soils, southern sierozem, and intrazonal soils: meadow and meadow sierozem soils forming combinations with meadow and common solonchaks. The southern light sierozem soils occupy the highest surfaces of the ancient alluvial plain-hilly foothills. The analysis of the fine-dispersed part of southern sierozems showed a mineralogical composition. In the upper horizons of irrigated sierozem soils of southern and meadow sierozem soils, the silt accumulation occurs, ranging from 14.5% to 18.9% and from 8.3% to 11.8%, respectively. The upper part of the irrigated sierozems profile (0–40 cm) has dominant hydrous minerals (27%–32%); however, their quantity decreased at the considerable depth. The maximum amounts of silicon oxide, phosphorus, and aluminum oxide were prevalent in the studied soils' arable layer. Compared with the soil, the bulk chemical composition of the silty fraction showed a decrease in the amount of SiO; however, a significant increase appeared in the gross Mg, Fe, and Al. In the arable layers, the enhanced content of hydromica revealed the hydrosludge process of the silty fraction. It occurs as a result of physical dispersion of mica material of large fractions and destruction of the small amount of smectite phase, reorganizing the fine-dispersed part of the soils due to irrigation.

Communicating Editor: Prof. Naqib Ullah Khan

Manuscript received: July 23, 2024; Accepted: September 30, 2024.

Citation: Songulov Y, Omirzakova A, Delibacak S, Ryspekov T, Yershibulov AK, Karabayev KB, Duisekov SN (2025). Mineralogical studies of the irrigated and non-irrigated sierozem soils in Turkestan Region, Kazakhstan. *SABRAO J. Breed. Genet.* 57(2): 761-771. http://doi.org/10.54910/sabrao2025.57.2.32.

Keywords: Mineralogy, irrigated and nonirrigated soils, sierozem, hydromica, layer formations, kaolinite, chlorite, quartz

Key findings: For the first time, the studies of silty fraction of southern and meadow-sierozem soils of Shaulder massif of Turkestan Region, Kazakhstan succeeded. The meadow-sierozem soils contain illite, glauconite (hydromica) kaolinite, halloysite, chlorite (clinochlorine), quartz, and feldspars. The magnesian aluminosilicates also accompanied the chlorite-kaolinite-hydrosludite association. Moreover, an observation took note of mineral trona occurring in non-irrigated meadow-sierozem soils. Irrigation for the known effects not only affects the humus state, physical, and chemical properties of soils, but also alters the conservative mineral component of the fine-dispersed fraction.

INTRODUCTION

Soil fertility is the natural ability of the soil to satisfy the plant needs for nutrients, water, and air. Particles composed the soil with different sizes. The percentage of mineral particle size distribution in the soil has its name as granulometric composition (El-Anwar *et al.,* 2019; Makhkamova, 2020). Analyzing the fertility state of the irrigated soils and evaluating the current state of the soil cover of agricultural lands in Turkestan Region, Kazakhstan is a must. This requires carrying out soil-geographical studies to describe the main physicochemical, morphological, and mineralogical properties of the virgin and irrigated soils of Southern Kazakhstan.

In Turkestan Region (ancient Otyrar oasis), the studied territory of Shaulder irrigation massif consists of heavy meliorative conditions with predominance of saline soils. In this massif, the salinity and tendency to secondary salinization of soils bear large influences from hydrogeological conditions of intensive external inflow and outflow of groundwater and intensive development of irrigation in South Kazakhstan (Saparov *et al.,* 2020; Ibraeva *et al.,* 2021). The soils of Shaulder irrigation massif belong to the foothill zone of low-grass semi-savannas—in vertical zoning of the Western Tien Shan.

The predominant components of the soil cover are the soils of semi-hydromorphic and hydromorphic moisture regimes, meadow, and meadow-sierozem soils, forming combinations with meadow and common solonchaks. Southern light sierozem soils cover the highest surfaces of ancient alluvial plain-hilly foothills. At present, the ground waters do not influence the soil-forming processes; however, due to genesis the lower part of the soil profile is characteristic of hydromorphic stage of development (Savin *et al.,* 2014; Laishanov *et al.,* 2016; Pachikin *et al.,* 2019).

The morphological features of meadow-sierozem soils are the higher thickness of the humus horizon, well-developed sod horizon, and absence of carbonate-illuvial horizon and visible carbonate segregations compared with sierozem soils. The surface accumulative humus sod horizon is brownish-light gray, with a dusty and clumpy structure. The next horizon's characteristic is a grayish-light-brown and a clumpy structure. The transitional humus horizon is light brown, with a slightly grayish tint and a clumpy structure, passing into the intermediate horizon with a light brown and loose clumpy structure. The soil-forming horizon is light brown (Mammadova*,* 2015; Karpenko *et al.,* 2016).

The light Southern gray soils have a superficial humus sod horizon of light gray. The horizon with a grayish-dark brown, slightly brownish, dense texture, and nutty structure gradually transforms into a horizon with a brownish, slightly grayish hue, dense texture, and dusty-nutty structure. The underlying carbonate-illuvial horizons vary in color, from light brown to muddy-light brown, with a dusty-colored and nutty structure. The subsoil horizon was yellowish-light brown, weakly compacted, and has a clumpy structure (Wang *et al.,* 2022).

In southern sierozem soils, the predominant plants were wormwood, bulbous bluegrass, mortuks, keireuk, flatbush, and the meadow species prevailing in small quantity. On meadow-sierozem saline soils, these have various halophytes. The soil and climatic conditions characterization and a systematic description of soils appeared in a past study (Pachikin *et al.,* 2019). The irrigated agriculture zones mainly involved alluvial plains of the Syr Darya and Arys rivers. Soil-forming rocks were loess and loess-like loams and weakly layered clay and loamy quaternary ancient alluvial deposits (Pachikin and Erohina, 2011). The study comprising variations in the composition of clay minerals in Southern gray soils under irrigation proceeded for the first time.

Southern low-carbonate soils of piedmont plains of Kazakhstan, with developed irrigation, differed distinctly from irrigated soils of Central Asia due to suspensions in the irrigation water and application of earthy fertilizers. Over the centuries, the formation of specific soils with different thickness and composition of agro-irrigation horizons surfaced. No accumulation of irrigation sediments in the study area materialized, and the soil does not contain silted soil. In irrigated gray soils of Bukhara and Samarkand oases, based on mineralogical studies, the hydromica with admixture of minerals with expanding lattice was evident. Tursynov (1970) reported a kaolinite-chlorite-hydrosludite association comprised fine sierozem fractions accompanied by montmorillonite, mixed-layer formations, and magnesian aluminosilicates.

The research about illitization and chloritization as a steady phase of transformation of fine weathering products in arid soil formation and construction of magnesian silicates as typomorphic clay minerals of a sierozem zone needs special attention. The similar conclusions about kaolinite-chlorite-hydrosludite composition of silty fractions of sierozems, accompanied by magnesian silicates, was notable in the study of the Central Kopetdag soils. Mineralogical studies of fine-dispersed fractions of loess and loess-like rocks of gray earth zone in 15 different regions of Central Asia showed a wide variety of minerals, including montmorillonite, beidelite, hydromica, kaolinite, halloysite, nonthronite, goethite, and fine-dispersed quartz (Sakbaeva *et al.,* 2012). However, reports mentioned hydromica and kaolinite as prevailing minerals, and very rarely a montmorillonite.

The presented research aimed to study the effect of irrigation on mineralogical and chemical composition of the fine-dispersed part of sierozems of Southern and meadow-sierozem soils of Shaulder irrigation massif of the Turkestan Region. The study also sought to develop a scientific basis of rational use of irrigated soils in the ancient alluvial plain of the Syr-Darya River, Kazakhstan.

MATERIALS AND METHODS

Mineralogical research of Shaulder irrigation massif soils of Turkestan Region, Kazakhstan happened for the first time. Irrigation transpired by the waters of Syr-Darya River, with slight mineralization (300–600 mg/l), and composition varied from hydrocarbonate-calcium to sulfate-magnesium. Soil transects and sampling locations are available in Figures 1 and 2. The objects of the comparative mineralogical study of the fine-dispersed part were the following soils:

Section P4/18 (arable land) – southern light gray soil, irrigated heavy loamy
Section P5/18 (virgin land) – light southern gray medium-loamy
Section (R9/19) (arable land) – meadow-sierozem irrigated, non-saline light loamy on loamy clay
Section P8/19 (virgin land) – meadow-sierozem-solonchak light loamy

Using the X-ray diffractometry method helped study the composition of soils silty fractions. The X-ray diffractometer analysis proceeded on an automated diffractometer DRON-3 with CцK-radiation and β-filter. The diffractogram conditions were U=35 kV, I=20 mA, shooting θ-2θ, and detector 2 deg/min. The X-ray phase analysis on a semi-quantitative basis progressed on powder sample diffractogram using the method of equal weights and artificial mixtures. Determining the quantitative ratios of crystalline phases ensued. The interpretation of diffractogram utilized the ICDD file data, i.e.,

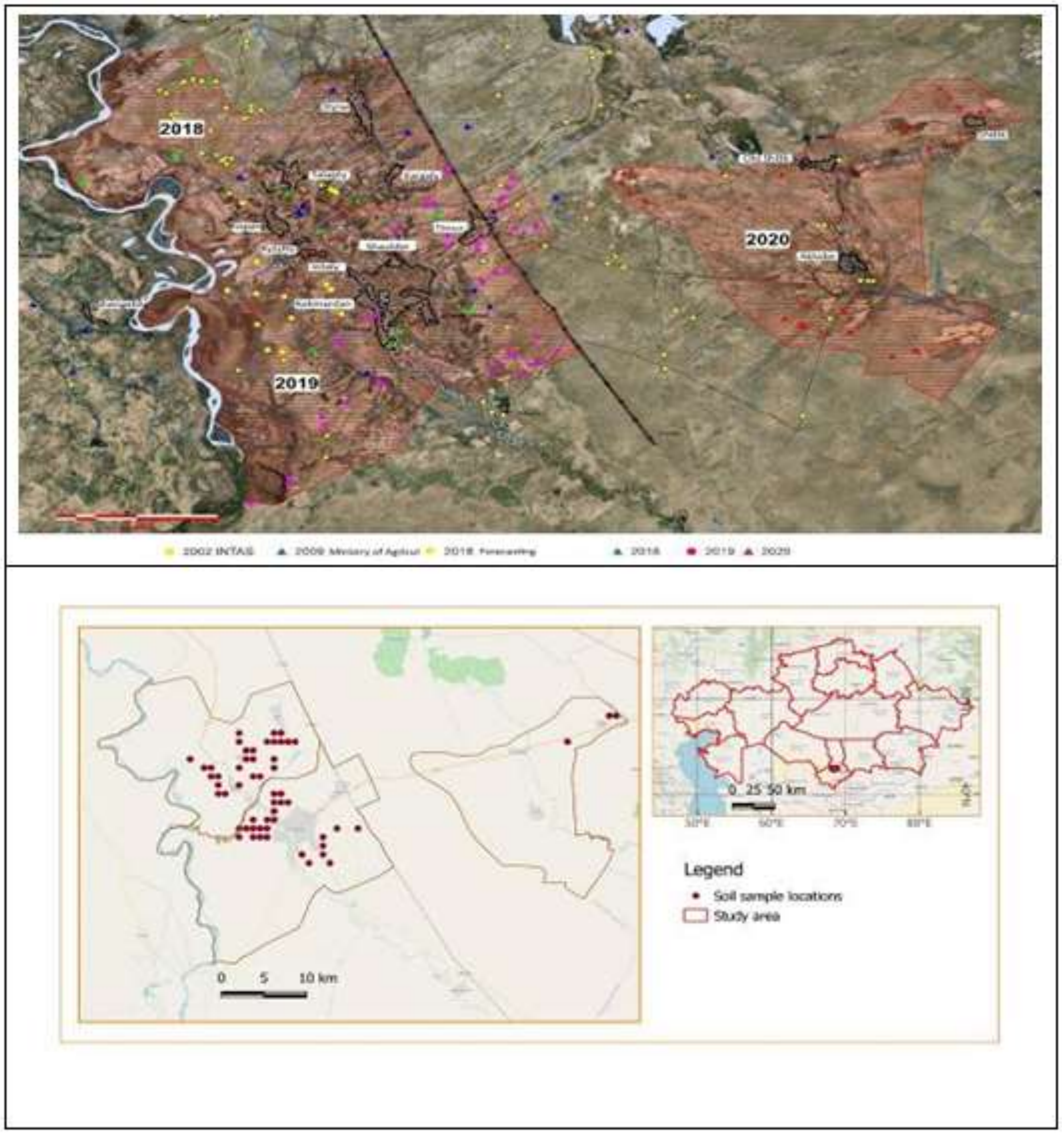

Figure 1. Location of soil transects and sampling sites.

Powder diffractometry database PDF2 (Powder Diffraction File) and diffractogram of impurity-free minerals (Figure 3).

The bulk composition analysis of the soil silt fraction employed the X-ray spectral microanalysis on electron-probe microanalyzer Superprobe 733, JEOL (Japan). Analysis of elemental composition and photographing of various types of radiation transpired using the energy dispersive spectrometer INCA ENERGY (Oxford Instruments) at accelerating voltage of 25 kV and probe current of 25 nA (Figure 4).

The basis of the research was the comparative-geographical method. The method, comprising comparison of soils, considered the different conditions of soil formation. It makes it possible to study the genesis of soils, to establish both genetic relations between the components of soil cover and factors of its differentiation, as well as, the main directions of the soil-formation process.

During the field work campaigns, the applied morphological methods provided reliability and validity of field soil diagnostics,

Figure 2. The soil profiles of Shaulder irrigation massif soils of Turkestan Region, Kazakhstan.

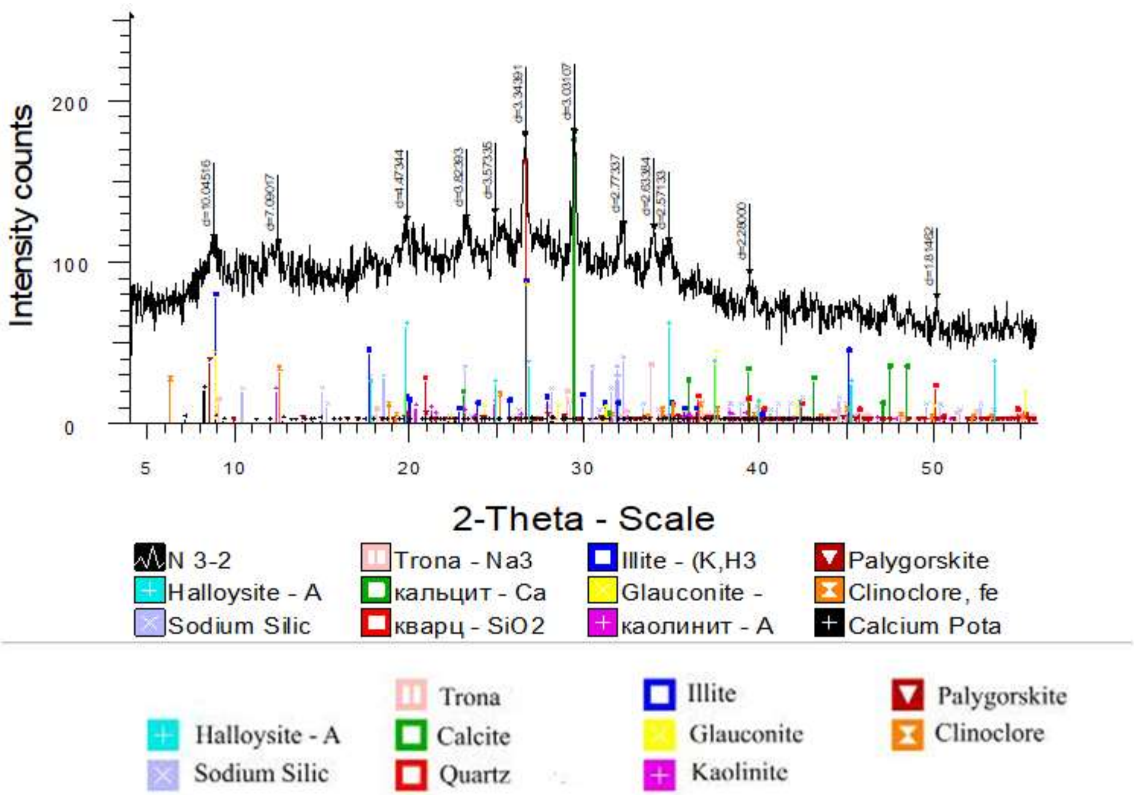

Figure 3. X-ray diffractogram of sample number 3 - 2 (P8/19, 20-30) meadow-sierozem solonchak light loam (virgin land).

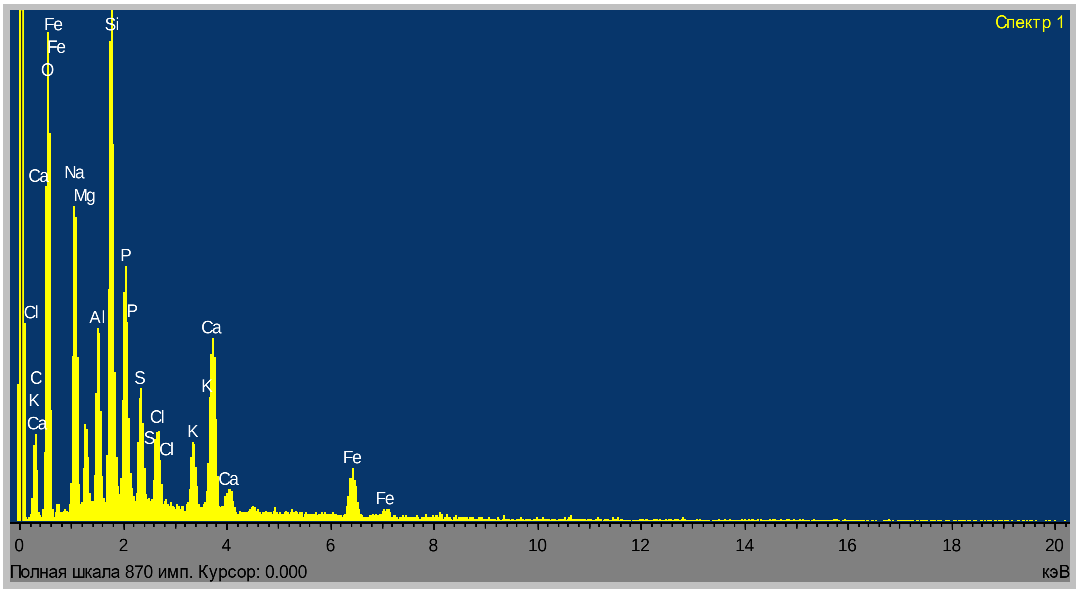

Figure 4. X-ray spectral microanalysis of the silty fraction of the elemental composition.

soil mapping, and characterization of the main morphological and mineralogical properties of the soils sampled to the parent rock. The application of instrumental methods correlated with laboratory analytical studies of the selected samples, carried out as per generally accepted methods (Churilin *et al.,* 2020).

RESULTS AND DISCUSSION

Overall, the studied soils showed relative homogeneity in the chemical composition of individual horizons. In Southern sierozem and meadow sierozem, the upper and middle parts of the profile have relative Ca and P oxides enrichment (Pachikin *et al.,* 2019). However, the slightly increased content of gross phosphorus and potassium in the upper horizons can refer to their biological accumulation. The distribution of MgO exhibited the contradictory trend, with its content slightly increased with the soil depth.

The gross chemical composition of the non-irrigated and irrigated soils in Southern and meadow-sierozem differed in the upper horizons. In irrigated soils, the calcium oxides and partially the magnesium, potassium, and sodium cations showed significant reduction compared with the virgin areas. The uneven distribution of SiO_2, Fe_2O_3, and Al_2O_3 in the profile of non-irrigated Southern sierozems soils can be due to the heterogeneity of mineralogical composition of initial loess-like rocks (Tables 3 and 4).

The gross chemical composition of the silty fraction of different genetic horizons of Southern sierozems and meadow-sierozem soils revealed a homogeneous characteristic because of the homogeneous nature of the mineralogical composition of the silty fraction (Tables 1 and 2). In the chemical composition, the differences in silty fractions of certain horizons of meadow-sierozem soils were nonsignificant and that may be due to unequal mineralogical composition of minor components, such as, hydromica (illite, glauconite) (Rau *et al.,* 2020).

In the silty fractions of the studied soils, the content of oxide elements also significantly differed. The amount of silicon oxides was lesser; however, a notable increase in gross magnesium, iron, and aluminum existed. Based on the involvement of the major components, the silty fractions of the horizons can be distinctly magnesium-ferri-aluminum-silicon fractions, accounting K_2O and Na_2O. The highest amount of silicon oxide, phosphorus,

Table 1. Bulk chemical composition of the silty fraction of Southern sierozem.

Depth (cm)	SiO_2	MgO	Al_2O_3	Fe_2O_3	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Na_2O	Total
Sample: Southern sierozem P4\C18 (arable land)												
All results in compounds (%)												
0-10	56.8	4.75	19.80	9.73	1.22	0.24	2.66	1.79	0.51	0.15	2.35	100.0
17-27	57.42	4.38	18.86	9.94	1.41	0.15	3.13	2.14	0.37	0.15	2.41	100.0
35-45	55.73	4.31	18.64	10.78	1.03	0.37	3.04	2.50	0.40	0.18	3.05	100.0
63-73	55.59	4.97	18.31	10.21	1.09	0.43	2.73	2.84	0.48	0.16	3.17	100.0
90-100	55.69	5.06	18.56	10.36	0.98	0.25	2.12	3.08	0.45	0.15	3.3	100.0
Sample: Southern sierozem (virgin land) P5\C18												
All results in compounds (%)												
Depth (cm)	SiO_2	MgO	Al_2O_3	Fe_2O_3	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Na_2O	Total
0-6	55.8	5.61	19.51	8.59	1.79	0.76	3.3	1.04	0.72	0.18	2.70	100.0
6-16	55.77	4.85	20.40	8.39	1.82	0.60	3.63	1.54	0.38	0.22	2.47	100.00
18-28	55.46	4.45	19.48	8.59	1.56	0.54	3.75	2.27	0.65	0.23	3.02	100.00
34-44	56.67	4.61	19.28	8.70	1.53	0.41	3.66	2.11	0.58	0.25	2.27	100.00
90-100	56.80	4.03	19.03	9.13	1.75	0.52	2.87	2.12	0.66	0.19	2.90	100.0

Table 2. Bulk chemical composition of the silt fraction of meadow-sierozem soil.

Depth (cm)	SiO_2	MgO	Al_2O_3	Fe_2O_3	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Na_2O	Total
Sample: meadow-sierozem soil P9\C19 (arable land)												
All results in compounds (%)												
0-5	56,80	3.91	20.51	7.49	1.88	0.52	3.80	1.77	0.73	0.22	2.37	100.0
20-30	56.75	3.85	20.20	7.69	1.71	0.60	3.83	1.74	0.78	0.42	2.43	100.00
34-44	55.76	3.95	19.58	8.09	1.61	0.64	3.56	1.27	0.65	0.33	2.56	100.00
50-60	55.87	3.81	19.28	8.50	1.63	0.71	3.76	2.51	0.78	0.35	2.80	100.00
Sample: meadow-sierozem soil P8\C19 (virgin soil)												
All results in compounds (%)												
Depth (cm)	SiO_2	MgO	Al_2O_3	Fe_2O_3	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Na_2O	Total
0-5	55.52	4.30	18.48	9.59	1.47	0.23	4.22	1.65	0.24	0.11	4.19	100.0
5-15	55.37	4.45	18.28	9.50	1.41	0.30	4.06	1.51	0.35	0.25	4.52	100.0
20-30	54.97	4.55	18.23	9.46	1.43	0.34	3.73	1.47	0.38	0.22	5.22	100.0
37-47	55.18	4.76	18.38	9.37	1.63	0.42	3.89	1.54	0.36	0.26	4.11	100.0
80-90	55.33	4.61	18.42	9.54	1.48	0.37	3.75	1.59	0.40	0.25	4.26	100.0

and aluminum oxide were evident in the plowing horizon of the studied soils (Tables 1 and 2).

Thus, as a result of the X-ray diffractometry study of fine fraction samples of the Southern sierozem and meadow-sierozem soils, the following distribution of clay minerals manifested (Tables 3 and 4). The main components of the silty fraction of Southern sierozems were the dioctahedral hydromica and its types with predominant occupation of octahedral belts of iron (ferrous illite), as accompanied by the kaolinite group, chlorite, palygorskite, quartz, and feldspars. Chlorite-kaolinite-hydrosludite association also had magnesian aluminosilicates complement. Mica-smectites with low content of smectite packages were visible in subordinate quantity. In meadow-sierozem irrigated and non-irrigated soils, mica-smectite mixed-layer compounds did not manifest. The study further revealed an interesting fact of trona mineral presence in meadow-sierozem virgin soils in the middle horizons (Figures 3 and 4).

Earlier studies of the silty fraction of the Northern and meadow-sierozem soils of the foothill plains located in the Zhetysu Range showed the following mineralogical composition of the Northern sierozems. These are mixed layer illite-smectite formations, hydromica, kaolinite, chlorite, lizardite, and non-clay minerals—highly dispersed quartz and

Table 3. Mineralogical composition of the silty fraction of Southern sierozem.

No	Depth(cm)	Silt content (< 1 µm)	Illite	Alternating-layer mineral	Glauconite	Chlorite (clinochlorine)	Quartz	Palygorskite	Kaolinite	Galloisite	Magnesia calcite	Potassium hydrophosphate	Feldspar (albite)	Microline
(P4/18) (arable land) Southern light sierozem irrigated heavy loamy														
1	0-10	18.88	16.8	3.3	12.5	12.6	12.9	8.3	9.1	7.7	4.9	4.0	4.7	3.2
2	17-27	17.21	15.3	5.1	11.6	13.1	12.7	9.5	8.7	6.3	5.0	3.8	4.9	4.0
3	35-45	18.28	11.6	6.7	12.6	14.8	12.0	8.8	8.9	7.2	5.5	2.5	4.8	4.6
4	63-73	14.38	8.5	8.2	11.2	13.9	14.1	10.1	9.9	7.1	3.4	2.7	5.3	5.6
5	90-100	15.55	8.4	9.1	11.7	14.2	12.5	9.7	8.6	6.9	4.9	2.6	5.6	5.8
(P5/18) (virgin land) Southern light medium-loamy sierozem														
1	0-6	17.76	12.4	15.7	8.3	9.2	15.1	5.9	11.2	5.0	4.2	1.5	6.3	5.1
2	6-16	16.08	11.3	15.2	7.3	10.7	14.8	6.0	10.7	5.4	4.3	2.2	7.1	5.0
3	18-28	15.38	10.1	13.0	6.9	12.0	14.3	6.5	11.6	6.2	4.3	3.5	6.4	5.2
4	34-44	19.85	11.0	13.0	7.2	11.3	15.8	5.7	10.9	5.5	5.1	3.2	6.7	4.6
5	90-100	14.98	11.7	14.1	7.5	11.2	14.1	7.8	11.8	4.3	4.9	2.3	5.9	4.4

Table 4. Mineralogical composition of the silty fraction of meadow-sierozem soil.

No.	Depth (cm)	Silt content (< 1 µm)	Illite	Glauconite	Sodium hydrate silicate	Chlorite (clinochlorine)	Quartz	Palygorskite	Kaolinite	Galloisite	Magnesia calcite	Trona	Potassium hydrophosphate	Feldspar (albite)
(P9/19) (arable land) Meadow-sierozem irrigated non-saline light loamy														
1	0-5	10.12	15.9	10.5	-	16.9	7.8	12.6	10.3	7.3	7.2	-	6.2	5.3
2	20-30	11.89	15.5	9.7	-	17.3	8.7	12.2	9.5	8.1	7.8	-	6.0	5.2
3	34-44	7.68	13.8	9.9	-	15.7	8.9	14.4	11.5	8.0	7.4	-	5.0	5.4
4	50-60	9.47	12.5	8.6	-	16.5	7.8	15.2	10.5	8.3	8.0		6.4	6.2
5		8.4	12.8	7.9	-	16.9	8.5	14.7	10.5	8.6	7.7		5.9	6.5
R8/19 (virgin) Meadow-sierozem solonchak light loam														
1	0-5	10.54	8.2	7.9	-	13.1	12.5	12.9	11.6	7.6	13.2	-	5.3	7.7
2	5-15	11.35	7.3	7.1	13.1	6.7	10.8	6.3	8.4	9.7	10.1	12.7	3.5	4.3
3	20-30	11.38	6.4	6.3	13.2	7.5	11.4	6.6	7.7	10.5	9.0	13.9	2.6	4.9
4	37-47	7.76	7.9	8.6	5.2	12.7	11.8	12.5	9.1	6.3	13.8	-	4.9	7.2
5	80-90	9.93	7.6	8.5	-	13.8	11.2	13.7	10.4	7.8	14.0		4.6	8.4

feldspars. The meadow-sierozem soils contain the mixed-layer formations, mica, magnesio arfvedsonite, kaolinite, chlorite, lysortite, ferro actinolite, quartz, and feldspars (Pachikin *et al.,* 2016; Omirzakova and Pachikin, 2018).

Northern sierozem soils developed in special bioclimatic conditions versus the Southern sierozem regions of Kazakhstan. The Northern sierozem differed from the Southern sierozem by low carbonate and irrigated from mountain water sources, as free from suspended particles. These, in turn, were sufficiently dominant in the irrigated water of the Syr Darya used in the fields of Southern sierozems with huge amounts of nutrients in solid and dissolved form (Gabdullin *et al.,* 2015; Pachikin *et al.,* 2017; Truskavetsky and Tkach*,* 2017).

Studies of irrigation effect on the Southern sierozem and meadow-sierozem soils showed accumulation of silt fraction in irrigated soils' upper horizons (Table 3 and 4). However, an increase in the hydromica content appeared in the arable horizons. These findings suggested silt accumulation was due to illites during aggradation processes of potassium fixation from various sources and dispersion of mica coarse material under irrigated conditions. Past studies enunciated the impact of irrigation on the mineralogical composition of chernozems, revealing an increase in the silt fraction from an enhancement in the labile minerals (Austin *et al.,* 2018).

Therefore, it is not necessary to correlate the process of hydrosludging of silt fraction only with the destruction of a small amount of smectite phase in the Southern gray soils. This was often the recognized data in previous studies comprising irrigation effects on chernozem soils. The hydrofluidization process of the silty fraction in the arable horizons was due to the removal of smectite, which prevails in the quantitative composition of chernozems (Alekseev, 2019).

In the irrigated Southern sierozems, the behavior of other minerals showed a slight accumulation of quartz in the upper horizons. A more intensive accumulation of illite than the quartz revealed that its accumulation was in the silty fraction, resulting from physical dispersion of mica material of large fractions in the irrigation process. There was no pattern in the distribution of kaolinite group along the profile of irrigated Southern sierozem and meadow-sierozem soils (Kunypiyaeva *et al*., 2023; Kenenbayev *et al*., 2024). A slight decrease showed in the amount of chlorite in the arable layer of Southern sierozem. The amount of feldspar (albite) and microline in the irrigated zone of the Southern sierozem in the arable horizon also decreased.

CONCLUSIONS

The obtained results indicate in the upper horizons of irrigated Southern and meadow-sierozem soils, silt accumulation occurred due to illite during migration processes of potassium fixation from various sources, as well as, the dispersion of coarsely dispersed mica material. However, in the arable horizons, an increase in the content of hydromica is noticeable, as well as, the redistribution in the finely dispersed parts of the soil due to irrigation, leading to ecological variations. Thus, the studied process of hydrosludge, an increase in the SiO2 content, and a change in the content of element oxides are due to the destruction of silicate minerals. These are a diagnostic sign of a change in the mineralogical composition of the Southern and meadow-sierozem soils of the Turkestan Region of Kazakhstan. Hence, irrigation should be a considered negative phenomenon.

ACKNOWLEDGMENTS

This research received funding from the Ministry of Agriculture of the Republic of Kazakhstan within the project BR06349612, "Problems of irrigated salted soils of the Turkestan Region and their solution based on the application of the innovative technology of soil fertility and crop yield increasing."

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