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The salt regime of the Manych Valley saline soil complexes

L P Iljina1*, K S Sushko1,2 and V Y Shmatko1
1 Southern Scientific Center, Russian Academy of Sciences, 41, Chechov ave., Rostov-on-Don 344022, Russian Federation
2 Department of Earth Sciences, Southern Federal University, 105/42, Bolshaya Sadovaya st., Rostov-on-Don 344006, Russian Federation
*Email: Iljyna@mail.ru

Abstract. The paper presents the results of researches on the regime of the Manych Valley saline soil complexes. The soil cover of the studied territory is characterized by a well-pronounced complexity, conditioned by the natural and anthropogenic factors’ interrelation. It was revealed that saline complexes consist of several varieties of soils, which are characterized by different salt regime and specificity of soil profile salinity. The degree and type (chemistry) of soil salinity have been determined. It was found that with an increase in the aridity index (NIA) in the series dry-steppe chestnut-solonetzic – saline – semi-desert saline complexes, the degree of salinity changes from slightly saline to highly saline, as well as the chemistry of soil salinity from sulfate-chloride to chloride-sulfate and chloride types.

1. Introduction
The Manych valley in the system of soil and physical-geographical zoning is located in the Don-Salo-Manych province. The soil cover is characterized by heterogeneity and complexity, which is due to the relationship between natural and anthropogenic factors. In this case, the leading role is played by the microrelief, the different nature of moisture, the level of mineralization of groundwater, the composition of saline soil-forming rocks, as well as anthropogenic impact (plowing virgin soils, knocking out soils as a result of high pasture load, using waters of increased mineralization for irrigation, et al.).

The structure of the soil cover includes dry steppe and semidesert soil complexes. Against the background of steppe cenoses confined to chestnut soils, on the one hand, spots of hygrophilous vegetation of micro- and mesodepressions on meadow chestnut soils stand out, and on the other hand, spots of semi-desert vegetation on chestnut solonetzic soils and chestnut solonetzes [1, 2].

In recent years, there has been a progressive salinization of the soils of the Manych valley. One of the important factors is the high salinity of the Manych water bodies and the tendency of its growth (mainly Lake Manych-Gudilo) due to the following main reasons: lack of river runoff, especially the Don one, low flow; the lithological composition of the rocks that make up the catchment, banks and bottom of reservoirs; return collector-drainage water from irrigation systems and pressurized groundwater with salinity 2.5–4.0 g/l [3].

In climatic terms, the study area belongs to the zone of insufficient moisture and a distinctive feature is aridity, which is associated with high temperatures in summer and little rainfall during the year. The HTC (hydrothermal moisture coefficient) is < 0.7, the amount of precipitation is 358–400 mm/year [1, 2].
The main parent rocks are carbonate and carbonate-sulfate loess-like loams and clays, clay gypsum (sulfate rocks), clayey and heavy loamy rocks of alluvial origin. Considering that loess-like rocks are saline, as a rule, they have an increased content of chlorides and sulfates of calcium and magnesium and, in particular, sodium, as well as the fact that readily soluble salts prevailing in the first meter layer are often higher than carbonates, in saline soils they get development of the processes of periodic rise of these salts up to solonetzic horizons [4, 5].

It should be noted that with the increasing aridization of the climate in recent years, the zonal dry steppe soils acquire significant solonetzism and salinity. In dry steppe conditions, poor wetting of positive surface elements in combination with significant wetting of negative forms due to runoff from the adjacent surface is the main reason for the formation of a high-contrast soil cover structure and intensive differentiation of vegetation associated with it [4–6].

2. Object and research methods
The study was carried out in 2016–2019 in Manych valley (Kumo-Manych depression, 46° 28' N, 42° 40' E), Rostov region (Pre-Caucasus) in vicinity of scientific field station «Manych» of Southern Scientific Center of RAS (figure 1).

Figure 1. Study area map.
When studying the soil cover, a comparative geographical method was used. In key areas with different climatic aridity index (NIA – aridity index is an indicator characterizing the degree of aridity of the climate), soil sections were laid, in which samples were taken from the genetic horizons, dried and prepared for laboratory analysis. Key areas with saline dry steppe soil complexes – the soils of the chestnut-solonetz complex (flat territory, protected zone of the Rostovsky reserve) and saline soil complexes (coastal areas of Lopukhovatoe, Krugloye, Lebyazhye lakes) belong to the moderate arid zone with NIA = 0.4–0.6 with average annual precipitation of 300–400 mm and warm summer. The saline semi-arid soil complex (border with Kalmykia, the key site "Kirasta") is located in the middle arid zone with NIA = 0.6–0.7 with an average annual precipitation of 250–300 mm and hot summer.

In laboratory conditions, the ion-salt composition of the aqueous extract was determined in soil samples of saline soils [7]. When establishing the chemism (type) and the degree of soil salinity, we used the classifications of N. I. Bazilevich and E. N. Pankova, as well as V. A. Kovdy and V. V. Egorova [7, 8].

3. Result and discussion

The water extract gives an idea of the content in the soil of water-soluble substances, both organic and mineral, consisting mainly of simple salts. The data of the water extract provide a good comparative material for the content and qualitative composition of water-soluble substances in the soil, and therefore this method is used for the genetic characterization of various soils. An analysis of the water extract of saline dry steppe soil complexes, including solonetzic chestnut soil and chestnut solonetz, showed that the upper horizon contains a small amount of salts, while in the middle part of the profile, one or several clearly pronounced maxima are observed, which indicates desalinization of the upper part of the profile and accumulation easily soluble salts at a certain depth due to the formation of an illuvial (solonetz) horizon. In the soils of the studied chestnut-solonetzic complex, the dry residue in the upper horizons does not exceed 1%, in the solonetzic horizons it is 1.2–2.1% (table 1).

The analysis of the qualitative composition of water-soluble salts revealed that in saline dry steppe soil complexes (chestnut-solonetzic) alkalinity from carbonates is present only in the solonetzic horizon of the chestnut solonetz and does not exceed 1.0 mg-eq/kg. Among anions, chloride is predominant, its content is uniform increases down the profile from 0.8–1.5 to 24.0 mg-eq/kg. For the sulfate ion, a similar pattern is observed – in the upper horizons its amount does not exceed 7.6 mg-eq/kg, and in underlying no more than 14.0 mg-eq/kg. The predominant cation for the chestnut solonetzic soil is calcium, its content increases down the profile to 1.8 mg-eq/100 g. Water-soluble magnesium is less and its amount does not exceed 7.6 mg-eq/kg. The maximum sodium content in the solonetzic horizons is 12.8–29.3 mg-eq/kg (table 1). According to the degree of salinity, the upper soil horizons are weakly and moderately saline, in the 25–50 cm layer they are highly saline (table 2). Saline soils, as a rule, have a slightly alkaline solution (pH = 7.5) from the surface, in solonetzic horizons, alkaline (pH = 8.0–8.5) and strongly alkaline (pH = 9.0), which is associated with the accumulation sodium ions in the middle and lower parts of the soil profile and indicates the presence of sodium bicarbonate in the soil solution (table 1).

For dry steppe solonchak soil complexes, it was found that a typical characteristic diagnostic indicator of the development of the salinization process is that in them the maximum amount of readily soluble salts is in the upper horizons, and it gradually decreases down the soil profile. Such a distribution of salts along the profile indicates a continuous rise of saline groundwater along the profile and their evaporation, as a result of which salinization of the entire soil layer occurs, and the upper horizon is continuously enriched with salts. All hydromorphic solonchaks are saline from the surface – the dry residue is 2.1–2.3%, while moving down the profile it decreases to 0.9–1.1% (table 1).

In the anionic composition, chloride is predominant; its content decreases uniformly down the profile from 5.2–7.6 to 3.0–4.8 mg-eq/kg. A similar pattern is observed for the sulfate ion: in the upper horizons, its amount does not exceed 5.7 mg-eq/kg, and in the lower horizons, it does not exceed 3.5 mg-eq/kg. The predominant cation for hydromorphic salt marshes is calcium, its content increases down the profile to 10.2 mg-eq/kg. Water-soluble magnesium is less and its amount does not exceed 3.2 mg-eq/kg. The
maximum sodium content in the surface horizons is 6.8–12.9 mg·eq/kg (table 1). According to the
degree of salinity, soil horizons up to a depth of 50 cm are highly saline (table 2). The soil solution has
an alkaline environment (pH = 8.0–8.5).

**Table 1.** Analysis of water extraction of dry-steppe and semi-desert saline soil complexes of the Manych Valley (in mg·eq/kg of soil).

| Sampling depth, cm | Dry residue, % | Alkalinity (by difference) | Cl⁻ | SO₄²⁻ | Ca²⁺ | Mg²⁺ | Na⁺ | pH |
|-------------------|---------------|----------------------------|-----|-------|------|------|-----|----|
| Soil chestnut solonetz complex (plain territory, a buffer zone of the reserve "Rostov") | | | | | | | | |
| Chestnut solonetzic (Sodic Kashtanozem) | 0–25 | 0.2 | – | 0.9 | 1.5 | 1.0 | 4.5 | 2.0 | – | 7.5 |
| | 25–50 | 1.2 | – | 8.5 | 15.4 | 4.8 | 10.5 | 5.4 | 12.8 | 8.0 |
| Solonetz chestnut (Solonetz Kashtanozem) | | | | | | | | |
| | 0–25 | 0.7 | – | 7.8 | 8.0 | 7.6 | 6.5 | 3.2 | 13.7 | 8.5 |
| | 25–50 | 2.1 | 1.0 | 15.4 | 24.0 | 14.0 | 17.6 | 6.7 | 29.3 | 9.0 |
| Saline soil complexes | | | | | | | | |
| (coastal territories of lakes Lopukhovatoe, Krugloye, and Lebyazhye) | | | | | | | | |
| Salt marsh hydromorphic typical (Solonchaks Gleyic) | | | | | | | | |
| | 0–25 | 2.1 | – | 3.2 | 5.2 | 3.5 | 3.0 | 2.1 | 6.8 | 8.5 |
| | 25–50 | 0.9 | – | 4.5 | 3.0 | 2.0 | 5.8 | 3.0 | 0.7 | 8.0 |
| Salt marsh hydromorphic typical crustal (Solonchaks Gleyic) | | | | | | | | |
| | 0–25 | 2.3 | – | 6.7 | 7.6 | 5.7 | 4.5 | 2.6 | 12.9 | 8.5 |
| | 25–50 | 1.1 | – | 5.4 | 4.8 | 3.5 | 10.2 | 3.2 | 0.2 | 8.0 |
| Saline semi-desert soil complex (border with the Republic of Kalmykia, the key area «Kirasta») | | | | | | | | |
| Light-chestnut salty (Caicic Kashtanozem Sodic) | | | | | | | | |
| | 0–25 | 0.1 | – | 0.6 | 1.1 | 3.3 | 6.4 | 3.7 | – | 7.5 |
| | 25–50 | 1.4 | – | 9.1 | 17.5 | 4.8 | 14.0 | 6.2 | 11.2 | 8.2 |
| Brown semi-desert salty soil (Endosalic Calcisoils Sodic) | | | | | | | | |
| | 0–25 | 0.5 | – | 1.7 | 1.9 | 6.7 | 3.8 | 2.3 | 4.2 | 8.1 |
| | 25–50 | 1.6 | 1.3 | 6.8 | 15.4 | 1.8 | 4.6 | 4.9 | 15.8 | 8.5 |

For the saline semidesert complex, including light chestnut saline and brown semidesert saline soils, it was found that they are weakly and moderately saline from the surface, the dry residue value does not exceed 0.5%, and all saline horizons are highly saline 1.4–1.6% (table 1). The anionic composition in the surface horizon is dominated by the sulfate ion 3.3–6.7 mg·eq/kg, and the chloride content increases down the profile to 15.4–17.5 mg·eq/kg. The predominant cation is calcium, its content increases down the profile to 14.0 mg·eq/kg. Water-soluble magnesium is less and its amount does not exceed 6.2 mg·eq/kg. The maximum sodium content in the illuvial horizons is 4.2–15.8 mg·eq/kg. The soil solution has an alkaline medium (pH = 8.1–8.5) (table 1).

Thus, it was found that with an increase in the aridity index in the series dry-steppe chestnut-saline-saline-semi-desert saline complexes, easily soluble salts accumulate in the soil profile, which is confirmed by an increase in the density of the residue from a slightly saline to a highly saline degree. All saline complexes are highly saline from the surface. The salinity chemistry of dry-steppe chestnut-
saline complexes is sulfate-chloride, saline complexes are mainly sulfate-chloride, saline semi-desert complexes are chloride-sulfate and chloride (table 2).

**Table 2.** Chemistry (type) salinity of the saline steppe and semi-desert soil complexes (composition of anions in mg·eg/kg of soil) and the degree of soil salinity (the residue value in the %).

| Sampling depth, cm | Cl⁻ | HCO₃⁻ | Salinity chemistry (type) | Degree of soil salinity |
|-------------------|-----|-------|--------------------------|-------------------------|
| **Saline dry-steppe soil complexes** |     |       |                          |                         |
| Soil chestnut solonetz complex (plain territory, a buffer zone of the reserve «Rostov») |     |       |                          |                         |
| Chestnut solonetzic (Sodic Kashtanozem) | 0–25 | 1.5 | 0.4 sulfate-chloride | lightly salted |
| 25–50 | 3.2 | 0.4 | sulfate-chloride | highly salted |
| **Solonetz chestnut (Solonetz Kashtanozem)** |     |       |                          |                         |
| 0–25 | 1.1 | 0.5 | sulfate-chloride | medium salted |
| 25–50 | 1.7 | 0.4 | sulfate-chloride | highly salted |
| **Saline soil complexes** |     |       |                          |                         |
| (Coastal territories of lakes Lopukhovatoe, Krugloye, and Lebyazhye) |     |       |                          |                         |
| Salt marsh hydromorphic typical (Solonchaks Gleyic) |     |       |                          |                         |
| 0–25 | 1.5 | 0.4 | sulfate-chloride | highly salted |
| 25–50 | 1.5 | 0.9 | sulfate-chloride | highly salted |
| Salt marsh hydromorphic typical crustal (Solonchaks Gleyic) |     |       |                          |                         |
| 0–25 | 1.3 | 0.5 | sulfate-chloride | highly salted |
| 25–50 | 1.4 | 0.7 | sulfate-chloride | highly salted |
| **Saline semi-desert soil complex** |     |       |                          |                         |
| (Border with the Republic of Kalmykia, the key area «Kirasta») |     |       |                          |                         |
| Light-chestnut solonetzic soil (Caicic Kashtanozem Sodic) |     |       |                          |                         |
| 0–25 | 0.3 | 0.1 | chloride-sulfate | medium salted |
| 25–50 | 3.7 | 0.4 | chloride | highly salted |
| Brown semi-desert solonetzic soil (Endosalic Calcisoils Sodic) |     |       |                          |                         |
| 0–25 | 0.3 | 0.2 | chloride-sulfate | medium salted |
| 25–50 | 8.6 | 0.4 | chloride | highly salted |

4. Conclusion

At present, under conditions of climatic variability (climate aridization) and anthropogenic impact, the structure of the soil cover of the Manych Valley is changing. On the terraces of Manych, the processes of xeromorphic soil formation and the formation of saline soil complexes are intensively developing, which are characterized by different salt regimes and the specificity of the salinity of the soil profile.

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