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Current state of saline soils in the Fergana Valley

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Abstract. Irrigation, groundwater and subsoil waters (soil solution) in the irrigated lands of the Ferghana Valley are integral parts of a chain in the formation, movement and accumulation of salts in the soil, and it is important to study them together in solving reclamation problems. In the process of soil formation, especially in the formation of optimal groundwater regime and balance in the conditions of valley irrigated soils, the role of subsoil waters is particularly large, has a multifaceted effect on the formation of saline soils, functions as the main source of salt in the soil in a certain situation; serves as a means of collecting (cumulating) dissolved salts and expelling them from the territory of irrigated and salt-washed areas (by means of ditches) in the second situation. The mechanical composition of soils plays an important role in the movement, redistribution and accumulation of dissolved salts in the vertical and horizontal directions along the soil profile.

1. Introduction

According to the literature, saline soils are soils that in their profile contain easily soluble salts in water in amounts that have a toxic (noxious) effect on agricultural crops. These include alkali soils, saltmarshes and brine spilled soils. Saline soils are mainly found in arid and semi-desert zones with arid and hot climates, and in runoff depressions, including Central Asia. The area of saline soils in the country is about 60% of the total irrigated land. The area of saline soils in the country is about 60% of the total irrigated land. There are primary, secondary, seasonal, spotted and mass salinity types of soil salinity, as well as surface and deep salinity according to the accumulation of salts. Current-modern residual and relict soil salinity are associated with the time of formation of soil salinity; brine and brine spilled, alkaline and nonsaline soils are divided according to the location of saline horizons in the soil profile, layer thickness and salinity degree; soils with chloride or sulphate and chloride or chloride and sulphate or sulphate are distinguished. Analysis of lithological and geomorphological, hydrogeological, soil-climatic conditions and human irrigation and economic activity of the Ferghana Valley shows that it is necessary to identify of important and specific laws of modern salt accumulation, to assess and forecast changes in the reclamation of irrigated soils. The causes and geochemistry of saline soils, including brine spilled soils, in the Ferghana Valley are very diverse. One of them, and the most important one, is the parent rock, which is distributed in dry climates and contains a variety of migrating salts. The relevance of the topic is the need to study the genesis of soils, the origin of salts, the laws of their migration, their accumulation and stratification in soils and groundwater, the processes of secondary salinization under irrigation with their own characteristics and laws in irrigated lands.

2. Study area and methods

2.1. Study area

The Ferghana Valley situated in Central Asia and spanning parts of Uzbekistan, Kyrgyzstan, and Tajikistan, is a region of significant geographical and cultural importance (Figure 1). Its rich history, fertile lands, and diverse

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ecosystems make it a compelling subject for research. This paper aims to present a comprehensive overview of the Central Ferghana Valley as a study area, with a focus on its geographical features, historical significance, socioeconomic dynamics, and environmental characteristics. Nestled between the Tian Shan and Pamir-Alay mountain ranges, the Central Ferghana Valley possesses a distinctive topography characterized by expansive plains, intersecting rivers, and fertile soil. Covering approximately 22,000 square kilometers, it plays a vital role as an agricultural hub, renowned for its production of cotton, fruits, and vegetables.

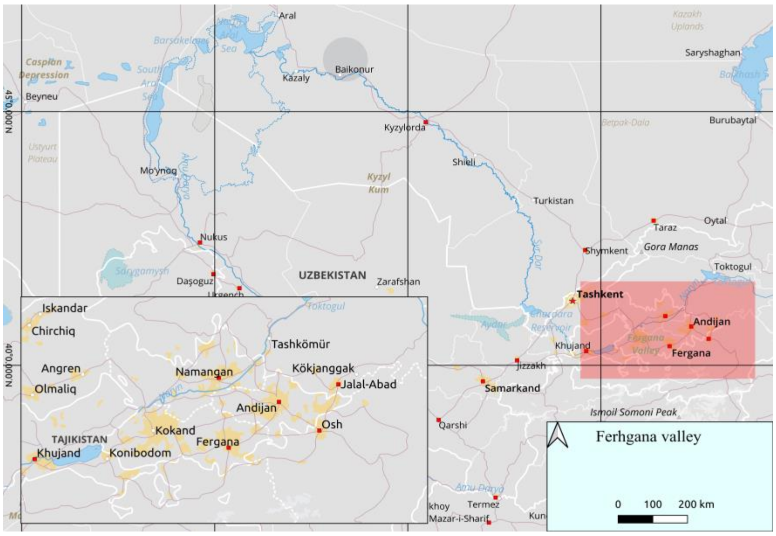

Fig. 1. Study area (source: www.naturalearthdata.com)

The valley is traversed by the Syr Darya River and its tributaries, which facilitate irrigation and shape the landscape. The deserts surrounding the Central Ferghana Valley are generally arid and semi-arid, characterized by sparse vegetation and limited water sources. These areas are marked by sand dunes, rocky terrain, and scrub vegetation that have adapted to the harsh conditions. The climate of these desert regions is characterized by hot summers and cold winters, with low levels of precipitation. Although the Central Ferghana Valley itself is not a desert, its climate and environmental dynamics are influenced by its proximity to these arid regions. Given its reliance on irrigation for agriculture and the potential impact of desertification from the surrounding areas, water management and conservation are crucial considerations in the valley. When discussing irrigation, groundwater, and subsoil waters in research papers concerning the Central Ferghana Valley, it is important to acknowledge the influence of adjacent desert ecosystems on the valley's ecology, hydrology, and environmental sustainability. Understanding the interactions between the valley and its surrounding desert regions provides valuable insights into the broader landscape dynamics of Central Asia.

2.2. Methods

The studies were carried out in field and laboratory conditions. Field studies were carried out on the basis of the "Methodology for conducting field experiments" of the former Uzbek Cotton Growing Research Institute; the analyzes were performed on the basis of the "Guidelines for the chemical analysis of soils" by E.V.Arinushkino. Laboratory studies of selected soil samples include the following methods: The water-soluble salt content using the water extracts method; the content of absorbed bases using the Pfeffer method modified by Kruger and Queen. The mathematical-statistical analyses of the results obtained were calculated by the dispersion method using the manual "Methods of field experience" by B.A.Dospekhov and Microsoft Excel. The statistical processing of the data was performed using multivariate and univariate analyses of variance (MANOVA and ANOVA), as well as a correlation analysis. The analysis was carried out using Statistica v12.0 and GraphPad Prizm v9.0.0 software.

3. Results and Discussion

The Ferghana Valley is a sedimentary lowland with an elongated ovoid appearance and a pot-like relief, with an area extended to 300 km from the west to the east and 70-120 km from the south to the north. This sediment is characterized by a sharp difference in relative heights. This shape of the relief, as well as the openness of 9-10 km from the West, allow the western winds to enter easily and survive for a long time. The central part of the valley corresponds to the deserts of Central Ferghana. Around it is a chain of gray soils with a semi-desert zone [1]. The whole history of the Ferghana Valley is associated with the transport and deposition of "solid currents", the movement and accumulation of geochemical compounds. At all stages of the development of the mantle, the process of salt accumulation is formed in certain small areas, in separate lithological and geomorphological and hydrogeological regions, changing the areas of movement from time to time in large areas or under tectonic influence. Currently, there are cases of different levels of salinity and salinity genesis of soils in Central Ferghana [2–5]. Thus, the natural conditions of the Fergana intermountain sediment (geomorphological location, lithological structure, hydrogeology, climate, lithomorphotectogenesis) are inherently heterogeneous loamy, nutritious and gypsum saline created the coating. Specific feature of the halogeochemistry of the soil cover of the Ferghana Valley is expressed in the blurring of the results of stratified geochemical flows under the influence of neotectonic phenomena. Often, in the same gypsometric level of the valley, there are layers of calcium and magnesium carbonates, layers of carbonate and gypsum mixture (food), pure gypsum layers, and even a mixture of all three components and slightly soluble salts. However, studies have shown that soils with a fully formed loam layer within the boundaries of the middle part of the conical distributions, and loamy soils in the periphery, and nutrient loams in the lake-proluvial plain and sand dunes. The hills and other foothills surrounding the Fergana Valley are occupied by alluvial-accumulative gypsum soils (gray and brown). The start of irrigation through the development of the deserts of Central Ferghana has led to an increase in groundwater levels and increased mineralization in the Central Ferghana region, resulting in varying degrees of salinization of newly developed lands, and in some places the formation of gypsum, carbonate salts and nutrients. Irrigated meadow soils in the Ferghana Valley have long been widespread and developed, and irrigated areas are widespread in Dangara, Furkat, Uzbekistan, Buvayda, Uchkuprik and Baghdad districts of the Kokand group (in recent years it has been found to be widespread in other parts of the valley). Large and large soil types in the Kokand group of districts, old and newly irrigated meadow-soil soils developed in the middle alluvial plains of the middle part of the Sokh River (Dangara district) require a detailed study as the area of our research. There are many classifications in determining the level of salinity of soils, which do not take into account the salinity (type), therefore, there are no errors or omissions in determining the level of salinity, there is a lack of accuracy in the indicators of salt reserves. Taking into account the salinity (types of salinity) in determining the level of salinity of soils is one of the most important indicators. This is because the amounts of salts in the same norms can represent different levels of salinity, depending on the chemistry of the salts, while at the same time having different toxic effects on plants. For example, the amount of salts in the dry residue of 0.8% indicates low salinity in soils of sulfate salinity types, moderate salinity in chloride-sulfate-type salinity and strong salinity in soils of sulfate-chloride salinity types (Table 1). The same quantitative indicators of salts are associated with an increase in the salinity of soils, a change in the sulfate salinity to sulfate-chloride salinity and, accordingly, an increase in the amount of chloride ion [6–10].

Table 1. Classification of determination of soil salinity by chemism of salts, x) % (Komilov O, Akhmedov A, 1983)

Level of salinity	**Types of salinity**					
	With sulfate	**With chloride sulfate**		**With sulfate chloride**		**With chloride**
	Dry residual	**Dry residual**	**Cl**	**Dry residual**	**Cl**	**Cl**
Nonsalted	<0,3	<0,1	<0,01	<0,1	<0,01	<0,01
Weak saline	0,3-1,0	0,1-0,3	0,01-0,05	0,1-0,3	0,01-0,04	0,01-0,03
Medium saline	1,0-2,0	0,3-1,0	0,05-0,2	0,3-0,6	0,04-0,2	0,03-0,1
Strong saline	2,0-3,0	1,0-2,0	0,2-0,3	0.6-1,0	0,2-0,3	0,1-0,2
Alkaline	>3,0	>2,0	>0,3	>1,0	>0,3	>0,2

x) - In the case of sulfate-type salinity, the degree of salinity is determined only by the amount of dry residue, in the case of chloride-sulfate and sulfate-chloride salinity by the amount of dry residue and chloride ion, and in the case of chloride salinity only by the amount of chlorine ion.

Salts involved in the formation of saline soils are the main elements in the formation of saline compounds - Ca, Mg, Na, K, Cl, S, N, V, Si, as well as the participation of Sr, Li and J and Vg in soil salinity. The migration of these elements and their accumulation in the soil is mainly the following hypothetical salts: chlorides - $NaCl$, KCl, $MgCl_2$, $CaCl_2$; sulfates - Na_2SO_4, $MgSO_4$, K_2SO_4, $CaSO_4$; carbonates - Na_2CO_3, $NaHCO_3$, $MgCO_3$, $CaCO_3$, $Ca(HCO_3)_2$; nitrates - $NaNO_3$, KNO_3; borates - $Na_2B_2O_2$ and others. Silicon dioxide dissolved in these salts is SiO_2xN_2O; silicates - Na_2SiO_4, K_2SiO_3, $CaSiO_3$ and humates of alkali metals can also be added (Kovda, 2008). The above salts affect cotton, grain, and other agricultural crops to varying degrees, some of which are completely harmless, some are less harmful, and some are very harmful. The range of effects of salts on plants depends on the amount of total salts in the topsoil (0-30 cm) of the soil, their solubility and type of salinity [11–13]. Salts like Na_2CO_3, $NaHCO_3$, Na_2SO_4, $NaCl$,

$Mg(HCO_3)_2$, $MgSO_4$, $MgCl_2$, $CaCl_2$ are harmful or toxic salts to plants. Although salts of calcium carbonate ($CaCO_3$), gypsum ($CaSO_4x2H_2O$) and magnesium carbonate ($MgCO_3$) are among the salts that are not harmful to plants, their high accumulation in the soil makes to grow crops very difficult, inhibits growth, makes difficult to cultivate the soil and wash away the brine. There are layers of gypsum, hydrogen sulfide (H_2S) toxic gas is released from anaerobic areas near groundwater, which has a negative impact not only on plants but also on human health.
Soil salinity is a form of desertification. Salinity intersects with major global challenges, including food security, desertification, and biodiversity conservation. Soil salinity reduces plant growth and productivity as a result of high salinity in the soil and adversely affects the biological activity of the soil. Saline soils cause osmotic stress in plants, reduce water absorption, and increase toxic levels of sodium and chloride. Different plants demonstrate resistance to different levels of salinity. Salinization removes arable land from production, leading to the abandonment of 0.3-1.5 million hectares per year worldwide. With proper drainage, salts can be washed away and the soil restored, but the problem of salinity persists where the water level is close to the surface [14–18]. Soil and magnesium sulfate salts predominate in the soil solution and groundwater in the Fergana Valley. Here, the accumulation of gypsum in the parent rocks and soils is common. Gypsum horned and fertile soils form large areas in the valley area. As a result of the development of the valley lands and long-term irrigation, the groundwater level has risen, a new cycle (phase) has begun of redistribution of salt reserves that have been dormant for thousands of years in the deeper layers of the soil (poor planning, low salinity, then over-irrigation, improper agrotechnologies, etc.) as a result of which secondary salinization processes have developed in these areas, as a result, previously groundwater was deep, non-saline soils became weak, moderate and strongly saline soils, large areas of saline soils were formed in some areas, and some fields were excluded from agricultural turnover. The most severe case of secondary salinization of soils is observed in weakly drained, poorly irrigated lands with constant drainage, the speed and activity of this process depends on the specifics of the natural conditions of the area (geomorphological and lithological structure, hydrogeological conditions, the nature of soils grounds, the amount of salts and their distribution on profile; on the other hand, the nature of land use depends primarily on irrigation conditions. In southern Australia, the replacement of deep-rooted perennials with shallow-rooted annuals has led to rising water levels and the development of a major secondary salinity problem. It is now recognized that landscaping requires the re-integration of perennial plants (trees, shrubs and forage) into the farming system. However, salinization processes continue in many areas because existing perennials are less profitable than annual crops. Have conducted research aimed at partially restoring the fertility of saline soils by growing salt-tolerant plants (halophytes) [19,20]. Many researchers point out that the use of halophytes to reduce salt concentration in saline soils can be slow (at best). One of the consequences of the use of groundwater by salt-tolerant perennials is the accumulation of salt in the root zone. This can cause great damage to the growth and long-term survival of the plant. Soil salinity is also a major pollution problem in Australia. To eliminate salinity, the concentrations of sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) in the soil existing in the roots and stems of natural grasses, Cynodon dactylon, and Thinopyrum ponticum were studied, and the accumulation of Na, K, Mg, and Ca ions was studied. Ponticum was found to be higher than C. dactylon. Therefore, C. dactylon has been suggested that it can be used as a salt accumulator in the cultivation and phytoremediation of plants in saline soils rather than T. ponticum [21]. In the soils of the desert region under the influence of natural and anthropogenic factors, it would be expedient to say that the amount of humus is not large, or rather small, as noted by most researchers. Humus is a complex structural substance in a changing state, constantly changing and renewing its composition. This change is primarily related to humic substances, carbohydrates, organic acids, alcohols, hydrocarbons, esters, aldehydes, nitrogenous substances, etc. We know that most of the organic carbon is in humus. The distribution and amount of humus in the soil is complex, it depends on external and internal factors. The amount of humus, its reserve and composition are among the important indicators for the soil. Almost all agronomic properties of the soil depend on the amount of these indicators, but at the same time under the influence of agronomic measures these indicators also change. *n*oted that saline soils account for 3.1% of the world's land area (397 million ha) and reflect the balance between soil organic carbon reserves (SOC) and loss of plant-derived carbon (C) from decomposition, leaching, and erosion [22]. Mechanisms controlling CO_2 transport and transformation in saline soils have been studied in Chinese soils [23]. They studied the electrical conductivity (EC) of different soils in a study from 2014 to 2018, explaining that saline soils absorb atmospheric CO2 at night and release it into the atmosphere during the day. It was concluded that saline soils, especially those with high EC, improve their ability to absorb carbon. *C*onducted research on the use of multi-source optical remote sensing data to map regional soil salinity [24]. Rational development and use of saline soils and saline resources, the use of Yellow River water in China in the event of a shortage of fresh water will ensure the growth of crops in the river delta [25]. High salinity affects large areas of newly reclaimed land in many coastal areas. The poor texture and properties of soils make the salt washing process inefficient. In studies [26] has been used to evaluate the effectiveness of salt washing in soils by adding gypsum and rice straw. They measured properties such as basic dissolved cations, permeability, and pH in soils. Treatment with gypsum and rice straw was the best in their experiments, with a decrease in the adsorption rate of sodium and the proportion of exchangeable sodium to 3.61%,

5.04% and 8.14%, respectively. High salinity is a serious global problem for many regions and it negatively affects the physicochemical properties of soils, reducing soil permeability, poor aeration and water supply [27,28] and ultimately negatively affecting agricultural production [28,29]. Reducing salinity by washing is usually necessary to improve soil quality, but the poor properties of soils make the process of washing salts very inefficient [30–34]. The high salt content in Jiangsu limits the regenerated coastal area and its role in agricultural production [35,36]. It will take several years to improve the soil by washing away the soluble salts in these soils. Drainage of salts is carried out slowly, resulting in deterioration of soil properties. To this end, it is necessary to add organic matter and chemical compounds to such soils in order to accelerate the washing efficiency of salts in the soil and improve soil properties. Numerous studies have proven that organic matter and gypsum (Ca_2SO_4 $2H_2O$) are the most widely used effective means of increasing washing efficiency. It is relatively inexpensive, common, and easy to use [37]. The purpose of adding gypsum is to replace the exchangeable sodium with calcium [38]. In cultivating agriculture, humus reduces and coordinates the strength of some adverse effects. An example of this is the situation when high levels of mineral fertilizers are applied without adequate consideration of soil and plant conditions. Humus increases the stability of the farming effect that occurs in the soil. Humus performs most of the functions in soil formation. The optimal amount of it, that is, humus in the soil, regulates the thermal regime, creating a valuable structure. According to the data collected so far, the initial decrease in the amount of humus is observed in the cultivated lands. There are many reasons for this. At the same time, there are also data that the amount of humus in irrigated soils increases with the level of their cultivation, but this increase is not unlimited, it occurs only in certain circles. In the virgin soil and desert regions, including the soils of Central Ferghana, the root system of plants is located in the upper layers of the soil, so the humus layer is small in these soils. Its reserves are also low compared to other soils. Changes in the amount and quality of humus in the soil under the influence of agriculture, especially as a result of the development of protected lands and the increase in the level of civilization of developed lands have been studied by many scientists [39]. The absorption capacity of soils, the composition of absorbed cations in them is reflected in the complete formation and fertility of the physical and chemical properties of the soil. According to the scientist who founded the study and management of the absorption capacity of soils and the amount of cations in them, it is possible to influence their fertility by controlling these properties of the soil. In saline soils, under the influence of anthropogenic factors (fertilization, reclamation, saline washing, irrigation, planting, etc.) changes the absorption capacity of the soil, the composition of absorbed cations, which can lead to both positive and negative consequences. Cations absorbed in the soil have different effects on the processes that take place in the soil due to their quantity, atomic radius, valence, activity. The cations are arranged according to their dispersion ability as follows:

Na > NH4 > K > Mg > Ca > B > H

It can be seen that the most dispersive property is specific to sodium and other monovalent cations. It should be noted that the absorbed cations are in active contact with the soil solution and therefore control the environment in the soil solution to a certain extent. At the same time, the soil solution and its composition affect the composition of the soil absorption complex. The absorption capacity of irrigated grassland saz soils in the desert region is insignificant in terms of the amount of cations absorbed. This is due to the low amount of humus and the mechanical composition of the studied soils in the desert region. Among the absorbed cations, calcium and magnesium make up the bulk. This is especially true for irrigated soils. The amount of absorbed calcium in irrigated soils is 38-65% of the total amount of absorbed cations, in the topsoil and subsoil this Figureure is 47-57%, the amount of absorbed magnesium in these soils reaches 33-51% in the topsoil and subsoil 33-40%. If we compare these indicators relatively, that is, if we pay attention to the degree of culture of the soil, then we see an increase in the amount of calcium absorbed and a decrease in magnesium with increasing irrigation period.

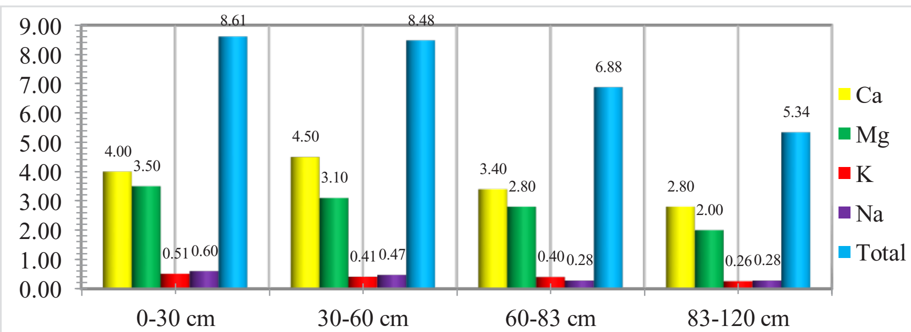

Fig. 2. The composition of the absorbed cations of newly developed meadow saz soils, mg-eq

This situation can be considered positive. If we compare irrigated soils with reserve saline, then a sharp increase in the amount of calcium absorbed in irrigated soils compared to saline soils and a relative decrease in magnesium can be seen in Figures. 1-4. The reasons for this are, firstly, irrigation and agro-technical measures, and secondly, the process of self-reclamation. The amount of potassium and sodium absorbed in the saline is 7-17% of the absorption capacity, while in irrigated soils it is 4-7%, i.e. if the saline is weakly saline, irrigated soils belong to the group of non-saline. Only the top layer of newly developed grassland saz soils can be included in the weakly saline group (6.97% of the absorbed sodium absorption capacity). In the studied soils, the absorption capacity in the saline ➝ newly developed ➝ newly irrigated ➝old irrigated direction, positive changes occur in the group of absorbed cations, the salinity level decreases and productivity increases, the gradual decrease in absorbed Mg stops within the typical range for these soils (33-50%) [40–42].
Depending on the amount and quality of absorbed cations in the soil, their environment, i.e. alkalinity, changes. Therefore, we believe that the determination and introduction into production of soils according to the formula $Na^{+} + K^{+} / Ca^{+2} + Mg^{+2} \times 100$, based on the coefficient of alkalinity and $Mg^{+2} / Ca^{+2} + Mg^{+2} \times 100$, gives good results.

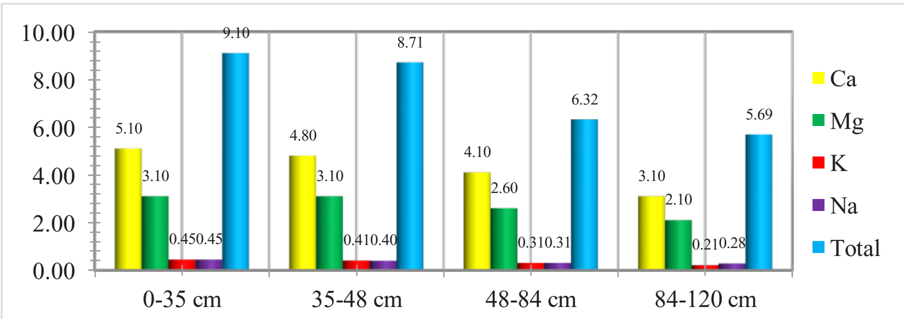

Fig. 3. The composition of the absorbed cations of newly irrigated meadow saz soils, mg-eq

The change in the proportion of absorbed cations in these soils, as in other hydromorphic soils, is due to the content of Mg and Na in groundwater. Mg absorbed in the groundwater of this region is high. Therefore, the content of Mg in the absorbed cations of the soil is abundant.

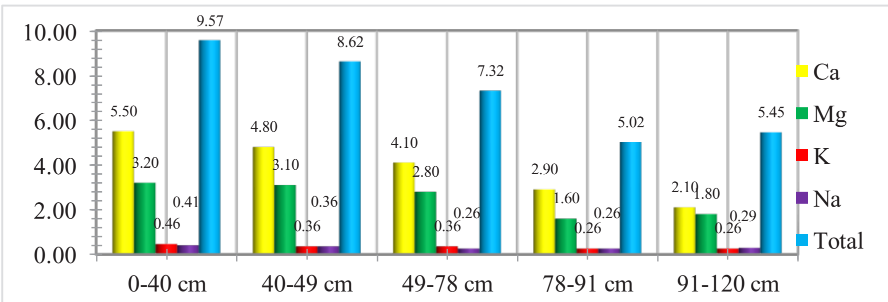

Fig. 4. The composition of the absorbed cations of old developed meadow saz soils, mg-eq

As the salinity of s subsoil water increases, the proportion of K, Na and Mg in it increases, which means that the proportions of these absorbed by the soil also increase. It was also found that there are some laws about the absorption of cations by the ionic radius and their absorption from the soil side.

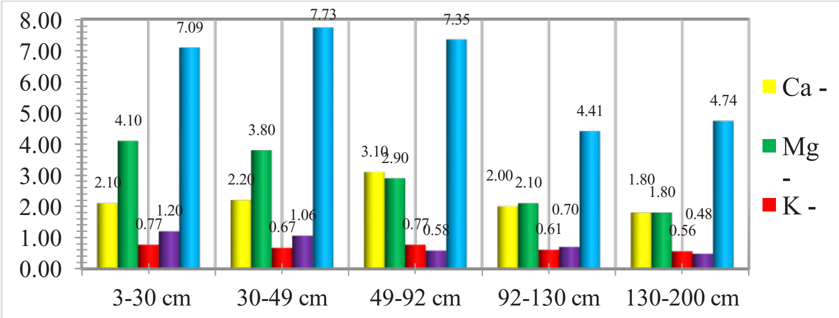

Fig 5. The composition of the absorbed cations of the salts, mg-eq

In particular, the oin of monovalent cations Na, K are 0.075, 0.133 nm that differs sharply from each other, but there is no sharp difference in the amounts absorbed in the drive and sub-drive layers. Hence, the absorption of K^{+} and Mg^{+2} by irrigated saline meadow soils does not appear to be almost independent of their ionic radii, since the absorbed amounts are close to each other, although the K ion radius is almost twice that of Na. The same situation can be observed for the cations Ca^{+2} and Mg^{+2}, i.e. the radius of the Ca^{+2} ion is 0.100 nm. while Mg^{+2} is 0.075 nm. However, the amount of absorbed Mg^{+2} is significantly lower than that of absorbed Ca^{+2}. This means that the effect of ion radius and clarke quantities on absorption is less noticeable. The reason for this is that Ca, Na, K clarkes are close, but absorbed differently. But it is expedient to continue research in this regard, because the exchange depends on the atomic and ionic radii of the elements, especially in minerals and rocks. Therefore, it is useful to study this process (absorption depends on the ionic radius) in the complex of soil absorption, that is, if we recognize that the colloidal particle is also a solid particle.

4. Conclusion

The emergence and development of saline soils, irrigated meadow soils in this region occurs under the influence of mineralized (78 g / l, 7-9 g / l) groundwater, winds and anthropogenic factors. The solution concentration of irrigated grassland saz soils is slightly higher, rising below the driving layer and is 11-18 g / l. With the increase in the degree of culture of soils, this Figureure oscillates around 10-14 g / l. 8-10 g / l in the layers in contact with groundwater.
In the first meter of the upper reaches of the sediments, this Figureure is 210-280 g / l. ni, 81-98 g / l in layers in direct contact with groundwater is formed. Irrigated grassland saz soils are poor in humus and nutrients, moderately saline, with an average content of harmful (toxic) salts of 0.6-0.7%. As the irrigation period increases, the amount of these salts decreases from 0.25 to 0.40% in the formerly irrigated soils. Rich in gypsum and carbonates. MgSO4 occupies a leading position in the composition of salts, indicating the presence of a separate province. The top layer of the newly developed group is weakly saline (5-7% of the absorbed Na absorption capacity), the remaining layers, as well as new and old irrigated separations are not saline. The absorption of cations by complex of soil absorption in irrigated soils depends on their ionic radius. The salts are weak and moderately saline, the amount of Na absorbed in them is 8-12% of the capacity of the absorbed cations. The absorption capacity of saline soils is 4.7-7.7 mg / eq, and in irrigated soils it fluctuates between 5.0-9.6, which is a low level for them.

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