Soil salinization under the large-scale irrigation agriculture along Ili River and Syr-Darya River

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Introduction

Salt-affected soils in North and Central Asia occupy more than 200 million ha, which corresponds to about 20% of the total area of such soils in the world (Szabolcs, 1986). In the former Soviet Union, many large-scale irrigation projects for the establishment of rice- and/or cotton-based agriculture were started in arid regions in Central Asia in the 1960s. This accelerated soil salinization around the farms in the area. According to Rozanov (1984), one million hectares of land was already lost in Central Asia due to erroneous irrigation practices. Khakimov (1981) stated that the percentage of moderate to severe salinized soils in irrigated areas reached 60 to 70%; and crop yields decreased by 30 to 33% in Kazakhstan. Nowadays, the situation is assumed to become worse due to an economic disorders in the countries of the former Soviet Union, disintegrated in 1991.

In order to avoid further increase in wasted land due to soil salinization, it is necessary to understand the dynamics of water and salts and to establish a proper guideline for controlling them under such large-scale irrigation agriculture. The authors investigated distribution pattern of salt-affected soils in and around rice- and cotton-based cropping fields along the Ili and Syr-Darya Rivers in southern Kazakhstan and Uzbekistan.

Materials and methods

Four irrigated areas in the Ili and Syr-Darya basins in southern Kazakhstan were selected for this study (Fig. 1). Brief description of the study sites and the sampling design are given below: Bereke (BK) is situated 250 km north of Almaty in the flood plain of the Ili River. The mean annual precipitation is 150 mm and an average air temperature is 9°C. The farm was established in 1979 and practiced four years rice-based crop rotation system: rice - rice - barley with alfalfa - alfalfa. Karaultube (KR) is located about 20 km east of Kyzylorda in the flood plain of the Syr-Darya River. The farm was established in the 1960s and had a typical seven years rice-based crop rotation system: rice - rice - rice - maize - wheat with alfalfa - alfalfa - alfalfa. The mean annual precipitation is about 150 mm and an average air temperature is 10°C. More than 3000 mm of irrigation water is applied for rice cultivation, whereas the upland crops are generally cultivated by high level of groundwater. To investigate the dynamics of salt species through the crop rotation systems in BK and KR, soil samples were collected from the surface 10-cm layer in each four or five points (BK1-BK8 and KR1-KR7) at different stages of the rotation systems. Soil samples were also collected from representative profiles in/around the irrigated field (BK34, BK104, KR11, and KR01).

Fergana Basin (FG), Uzbekistan, is one of the most famous region of cotton cultivation. Annual precipitation is about 150 mm and average air temperature is 16°C. The Syr-Darya River penetrates the central part of the basin from east to west and southern part of the river is used for irrigation agriculture. In this area, soil samples were collected from selected profiles at different locations against the Syr-Darya River. On the other hand, Dzhetysay farm (DZ) (Kazakhstan) and Syr-Darya region (SD) (Uzbekistan) are located in the south-western plain of the middle part of the Syr-Darya River. Soil samples were collected from representative profiles. In these areas, upland crops, including cotton, are planted continuously. The amount of irrigation water for cotton cultivation is approximately 800 mm per year.

The soil samples were collected, air-dried and passed through 2 mm mesh sieve for following chemical analyses: pH and contents of water-soluble cations and anions (saturation paste and 1:5), gypsum content, and particle size distribution. Additionally, water samples were collected from irrigation and drainage canals and analyzed for pH, electric conductivity (EC), and concentration of each component.

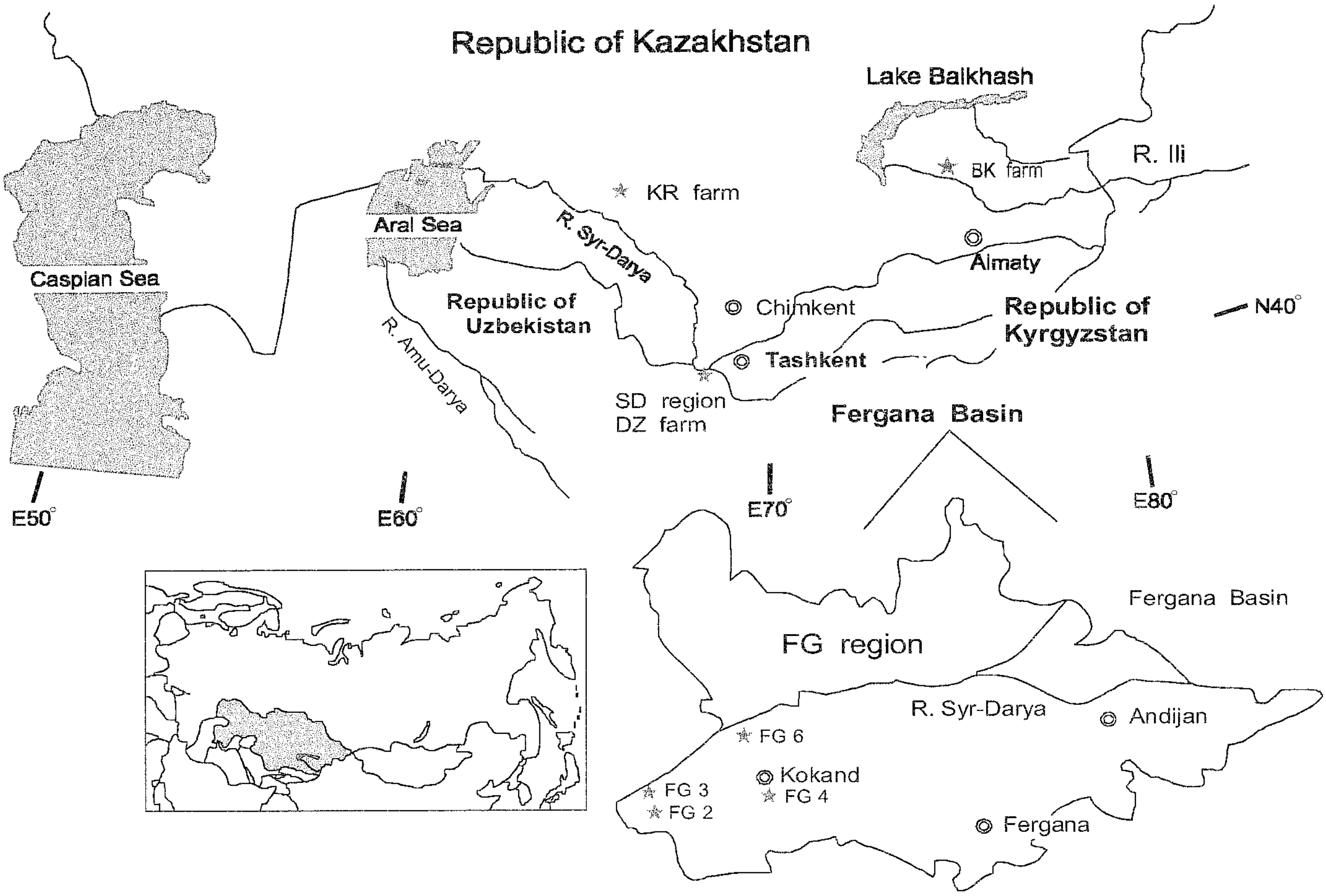

Fig. 1. Study sites. BK: Bereke; KR: Karaultube; FG: Fergana; DZ: Dzhetysay; SD: Syr-Darya.

Results and discussion

1. Salt dynamics observed in the rice-based crop rotation systems in the BK and KR farms

Paddy cropping phase. Figure 2 shows the contents of soluble salts (soil: water = 1:5) in the surface 10-cm soil layers at different stages of the crop rotation in BK and KR. Although the data presented here varied widely, the contents of soluble salts generally decreased in the period of rice cultivation, which implies that waterlogging washed out salts accumulated during the period of upland cropping. However, considerable amount of salts still remained in the paddy fields in the KR farm and the BK5 plot. Thus, salt-washing mechanism failed to operate effectively at these fields. According to the field observation, the drainage system in the KR farm did not work effectively and BK5 was situated at a unique location that lacked any drainage canals. An increasing groundwater level around the KR farm, which was located in a relatively lower part of the flood plain, may hinder field drainage, resulting in high salinity in the farm.

Upland cropping phase and uncultivated plot. Figure 3 shows distribution of the water-soluble salts, gypsum, and SAR with soil texture in the representative soil profiles both in the upland cropping and uncultivated plots near irrigation canals in BK and KR. The soluble salts usually accumulated at/near the surface with a concomitant increase of SAR in these plots. In the uncultivated plots (BK104 and KR01), soil salinity was often much higher than in the cropping plots, presumably because of cumulative effect of soil salinization there. A significant amount of gypsum was detected only in the upper layers of uncultivated plots. Judging from the water table (1 m), the water with salt ions moved upward due to intensive evapotranspiration, resulting in the accumulation of gypsum and/or soluble salt at/near the soil surface.

Figure 2 allowed to estimate the rate of salt accumulation in the surface 10-cm soil layer during the upland cropping phase in BK. Soil salinization started after the termination of rice cultivation in the first year of upland phase at relatively high water table, and then gradually advanced in the second year. The annual rate of salt accumulation during the first year exceeded 40 kmole ha^{-1} y^{-1}, sulfates of *Ca* and *Mg* being dominant salt components, while in the second year it was about 25 kmole ha^{-1} y^{-1}. Accumulation of *Na* salts was considerable.

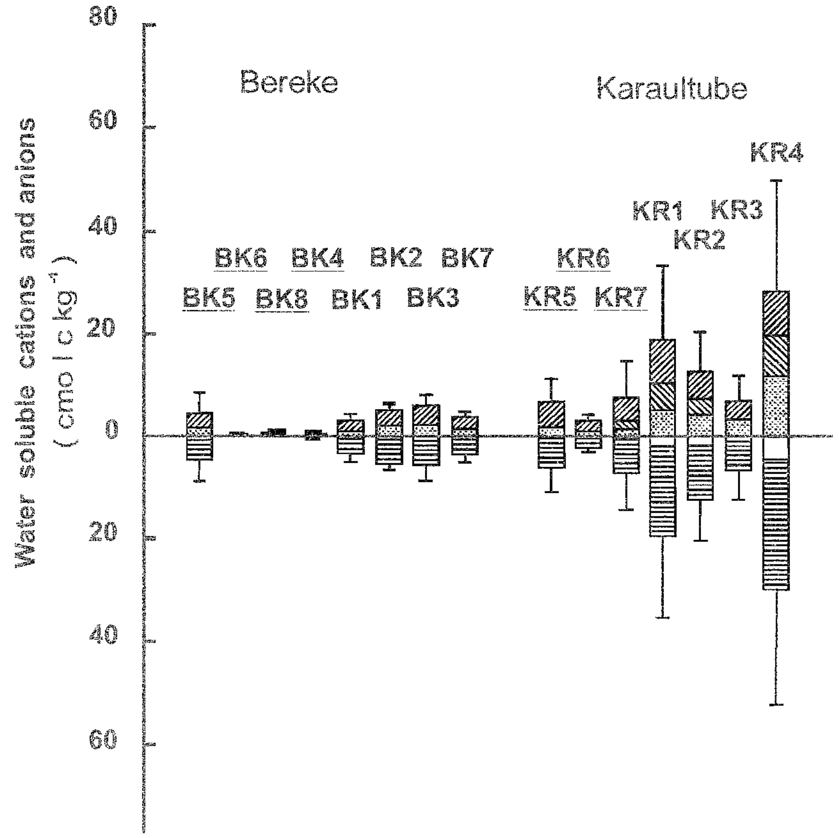

Fig. 2. Contents of water soluble salts (1:5) in the surface 10 cm soils in relation to the land rotation systems in the BK and KR farms (samples under paddy cropping are underlined).

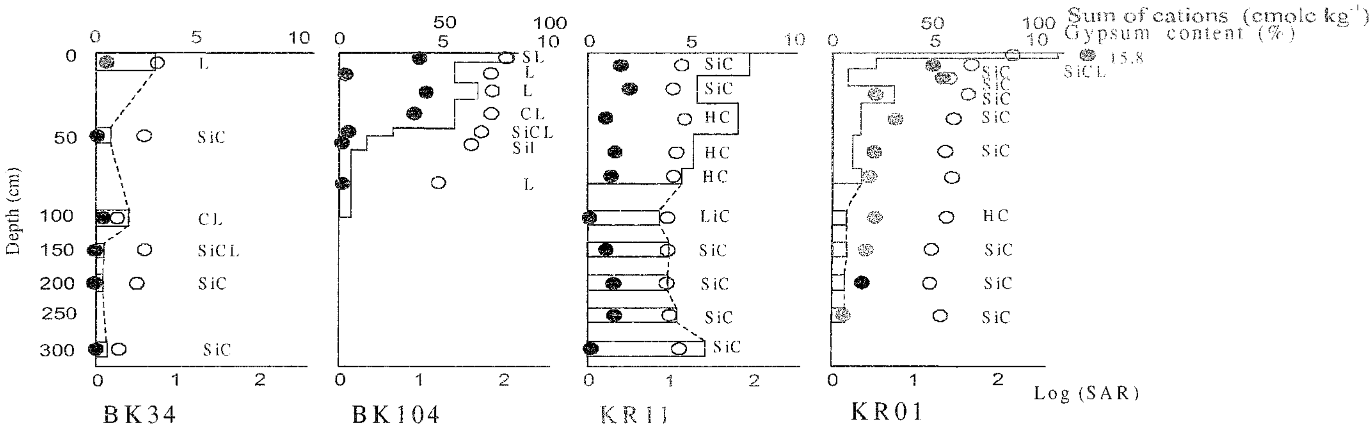

Fig. 3. Distribution patterns of the water-soluble salts (□), gypsum (●), and SAR (log (SAR): O) with soil texture in the representative soil profiles both in the upland cropping and uncultivated plots near irrigation canals in BK and KR.

It is noteworthy that such a soil salinization rate may be much larger in some places of KR. It is concluded that the rice-based irrigation agriculture is sustainable under an appropriate supply of irrigation water with a proper drainage system. The situation in KR is, therefore, a quite risky one.

2. Soil salinization observed in the cotton-based crop rotation systems in the FG and DZ/SD regions

FG region. Figure 4 shows distribution of the water-soluble salts, gypsum, and SAR with soil texture in the soil profiles of cotton-based cropping field. There were generally few problems of soil salinization in FG. The accumulation of soluble salts and gypsum, with a concomitant increase in SAR, was observed only in the uppermost layers of FG3, located at the lowest part of the basin. This fact suggested that the upward movement of water and salts, which was typically observed in/around the rice-based field, occasionally occurred in this lowest location of cotton-planted area. FG6 was also located in the center of basin and showed some salt accumulation through the profile.

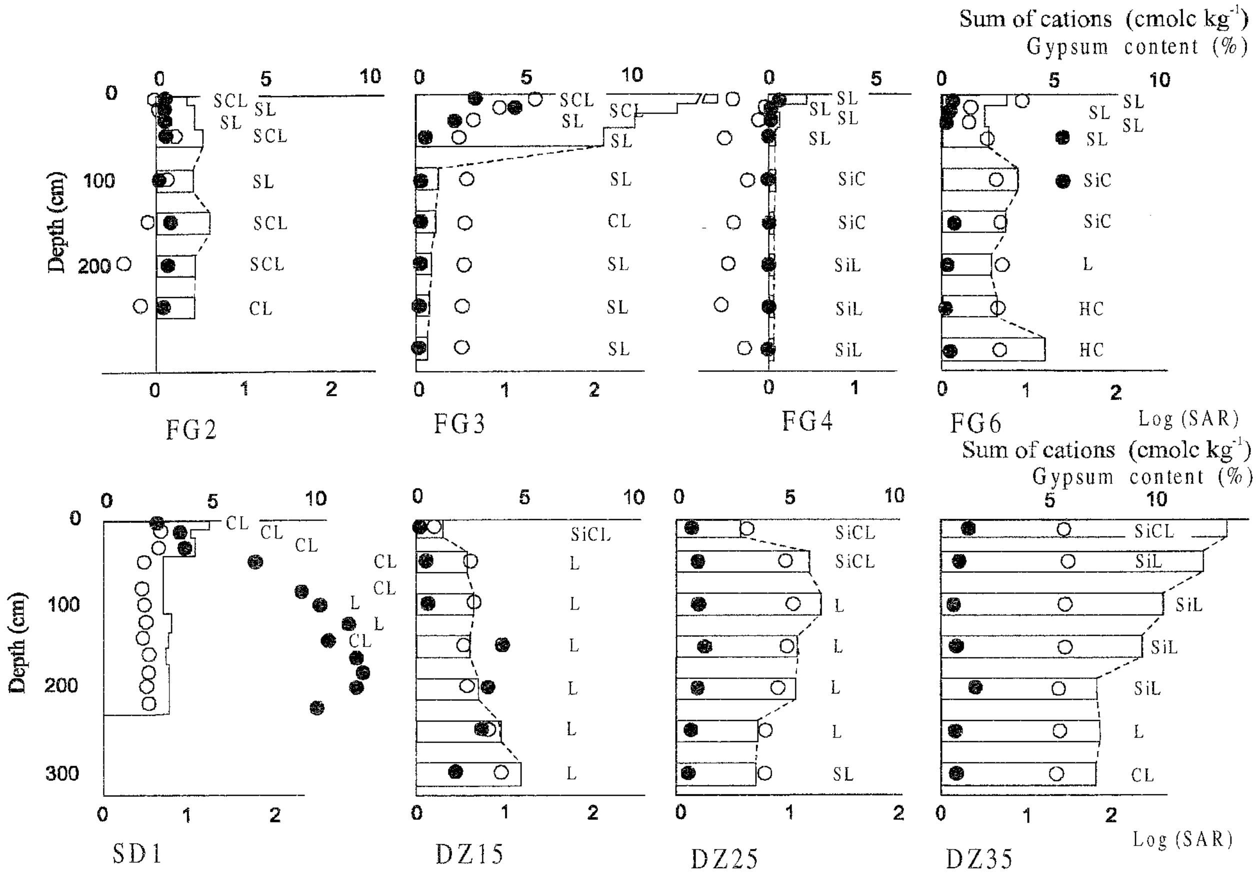

Fig. 4. Distribution patterns of the water-soluble salts (□), gypsum (●), and SAR (log (SAR): O) with soil texture in the representative soil profiles in the cropping fields of the FG and SD/DZ regions.

At higher location, against the Syr-Darya river (FG2 and FG4), soluble salts scarcely accumulated at any layers in the soil profile. Quite low SAR of the soil extract reflected good quality of the irrigation water from the Soh River, a tributary of the Syr-Darya River (see Table 1). Additionally, relatively light texture of the soils and a favorable drainage can provide sufficient leaching of soluble salts. Nonetheless, high contents of gypsum was often detected in deep layers of soils, suggesting that the amount and/or effect of irrigated water here was not intensive enough for leaching as in the rice-based systems.

Table 1. Chemical composition of the irrigation and dranage water.

	EC	Na	Mg	Ca	Cl	SO_4	HCO_3	Sum of cations	Sum of anions	SAR
	($mS\ cm^{-1}$)				($mmolc\ L^{-1}$)					($mmol\ L^{-1})^{1/2}$
BK farm										
Irrigation water from R. Ili	0.60	1.6	1.6	2.5	1.0	2.2	2.8	5.8	5.9	1.12
Dranage water	0.85	3.2	2.4	3.4	1.4	3.5	4.2	9.1	9.2	1.89
KR farm										
Irrigation water from R. Syr-Darya	1.64	5.9	5.2	4.5	2.5	11.5	2.3	15.8	16.3	2.65
Dranage water	4.44	24.3	19.2	14.0	10.9	37.8	4.6	57.6	53.3	5.95
FG region										
Irrigation water from R. Soh, a tributary of R. Syr-Darya (FG2 and FG4)	0.32	0.3	0.8	2.2	0.1	1.4	2.0	3.4	3.4	0.27
Irrigation water from R. Syr-Darya (FG3 and FG6)	1.34	4.3	4.5	5.9	2.2	9.5	2.9	14.8	14.6	1.89
Dranage water from the main collector to R. Syr-Darya	2.89	9.4	11.3	13.2	4.6	27.3	2.7	34.4	34.5	2.70
SD/DZ region										
Irrigation water from R. Syr-Darya	1.34	3.7	4.5	5.4	1.9	8.7	2.4	13.7	13.0	1.65
Drainage water	2.38	8.9	8.4	9.6	3.9	20.2	3.0	27.1	27.1	2.97

SD/DZ region. The present soil salinization varied widely in SD/DZ. High amounts of soluble salts were accumulated in subsoils in DZ25 or came up even to the surface layer in DZ35. This may be a secondary salinization due to an incomplete drainage induced by a serious economic crisis in recent years. Silty to loamy soil textures in the SD/DZ region may make a comfortable drainage more difficult. It is estimated that, without leaching, approximately 10 kmole ha^{-1} y^{-1} of soluble salts could be added to soil profile by the application of 800 mm of irrigation water from the Syr-Darya River and, therefore, would bring a serious soil salinization within a few years.

It is concluded that comfortable drainage condition is urgent for a sustainable production at the cotton-based irrigation agriculture. However, initial soil features, such as texture or salt contents, varied greatly in each region. Recently, the situation is getting worse to sustain the effectiveness of the drainage system, especially in the unfavorable region, such as SD/DZ.

3. Chemical composition of irrigation and drainage water

Chemical composition of the water from the irrigation and drainage canals of the study sites is given in Table 1. Both EC and SAR of the irrigation water were higher in the Syr-Darya River than in the Ili River or small tributaries of the Syr-Darya River in FG. According to the criteria of evaluation of the quality of irrigation water, based on EC and SAR (U.S. Salinity Laboratory Staff 1953), the irrigation water from BK was classified as C2-S1 and that from KR or SD/DZ was C3-S1. Thus, the farms in the the Syr-Darya basin have higher potential for soil salinization by addition of salts from irrigation water than those along the Ili River.

On the other hand, higher salt concentration in the drainage water than in the irrigation water in each farm indicated that fairly high amounts of soluble salts, accumulated in the soils, were washed out. Sustainable land use, especially in the rice-based cropping system, with intensive salinization during the upland cropping phase, by continuously high water table, requires a high-capacity drainage system for washing out the salts at the paddy phase. But some areas around the lower part of the Syr-Darya River, i.e. the KR farm, were already affected by severe soil salinization due to an incomplete drainage. The significance of drainage conditions also applies to the cotton-based system, especially in the region with originally high salinity and/or fine texture (such as SD/DZ). However, an abandunt irrigation with proper drainage system may cause a luxury consumption of water and therefore induce several environmental problems. It is questionable that the irrigation agriculture in this region will be sustainabile against soil salinization and/or adverse environmental impacts in near future.

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