Research article

Influence of Soil Salinization on Growth of Cotton in an Arid Area in Northwest of China

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Abstract This paper discusses the influence of soil salinization on cotton plant growth and the factors that cause salinization in irrigated farmland located along the northern part of the Tarim River, Xinjiang Uygur Autonomous Region, China. A field survey was conducted in a cotton field in Nuerbake Township, Xayar County. The physical properties of the soil, fluctuations in groundwater level, the growth of cotton plants and electrical conductivity (EC) of the soil saturation extract were investigated. The quality of irrigation water and groundwater was also measured at the study area. The groundwater level was low in the summer and high in early spring; this high level was due to thawing of the soil and irrigation for planting. However, use of border irrigation temporarily raised the groundwater level. Even within the same field, the EC of the soil saturation extract differed depending on locations and soil depths. An EC of the surface soil exceeding 8.0 dSm^{-1} retarded cotton growth. We found that irrigation water quality did not affect the growth remarkably because the EC of the irrigation water was lower than 4.0–6.0 dS/m. On the other hand, the existence of a less permeable subsurface soil damaged cotton growth. The difference in hydraulic properties of the subsurface soil is influenced by the amount of clay that affects water and saline movement toward the surface.

Keywords electrical conductivity, soil saturation extract, salinization, irrigation

INTRODUCTION

The degradation of fields by soil salinization causes decrease in crop production. Soil salinization is a serious problem in arid and semi-arid regions (Jan van S., 1994), and it is a chronic problem in Xinjiang, northwest China. In Xinjiang, the agricultural field under salinization influence is about one-third of the total cultivated field (Hou, Z. et al., 2007). At the same time, soil salinization becomes a serious problem with the increase in irrigation agriculture (Yamamoto, T. et al., 2006).

The factors affecting soil salinization have been delineated in several past studies. In this area of China, soil salinization is the result of several factors, namely; 1) soil and groundwater contain large amount of saline; 2) the groundwater level is kept high and 3) soil moisture and saline move to the surface by evapotranspiration under the above-mentioned conditions.

However, the groundwater level may not be a direct factor of soil salinization in Xayar, China, because salt accumulates in the farmland where groundwater level is sufficiently deep (Nagasawa, T. et al., 2008). Moreover, little research has been done on crop growth and soil salinization, and fundamental data are needed to counter this problem in the future. Therefore, in this study, we considered the factors involved in soil salinization and its influence on cotton growth in the Tarim River Basin.

METHODOLOGY

Outline of the investigation area

The investigation targeted Nuerbake Township of Xayar County, which is located in the Taklimakan Desert in the northern border region of Xinjiang Uyghur Autonomous Region. Xayar County is located downstream of the Ugen River, which is a branch of the Tarim River (Fig. 1). The temperature ranges from −30°C to 40°C, and annual precipitation is about 50 mm in this region. Here, soil freezes during the winter. The primary local crop is cotton, and irrigation water relies on the Kyzyl Dam located upstream of the Ugen River. The method of irrigation is mainly border irrigation.

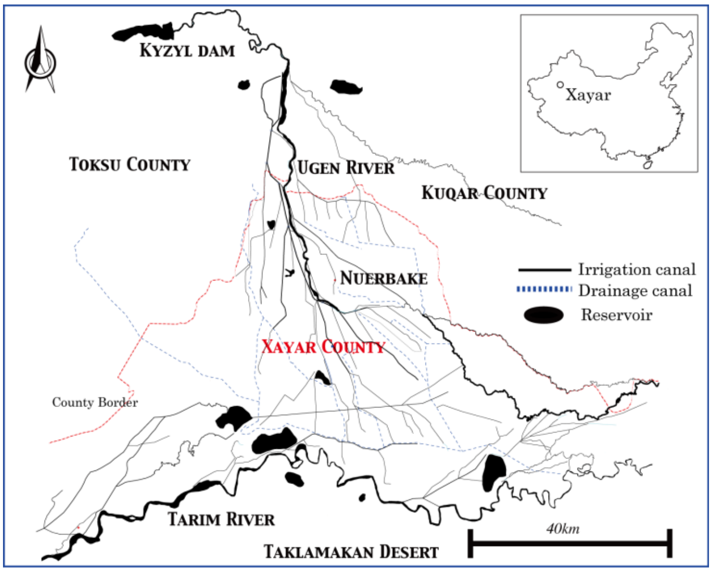

Fig. 1 Outline of Xayar County

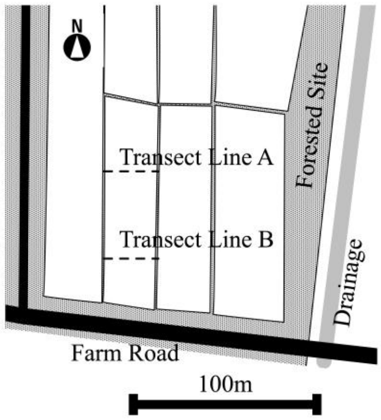

Fig. 2 Investigation field

The sampling of the irrigation, drainage, groundwater and well water was performed in Xayar, particularly in the Nuerbak Township in 2006–2010. The electrical conductivity (EC) was measured onsite, and water quality was analysed for anions and cations with Japanese Industrial Standards (JIS).

The EC of soil saturation extracts in a farmland damaged by salt accumulation was measured. In addition, a soil survey of the farmland and groundwater level measurement was conducted. The surveyed farmland was located near a drainage ditch and consisted of cotton fields where the growth of cotton was uneven and salt accumulation was relatively troublesome (Fig. 2). We measured plant heights and collected soil samples from this farmland. The survey was conducted during the flowering period in early August 2008 at two places, namely: along the A Line extending in the east to west direction at 40 m north of the farm road where the growth of cotton flowers was uneven and sporadic bare areas could be seen on the ground; and, along the B Line extending in the east to west direction at 12 m north of the road where plant growth was relatively even. Along both the lines, from points 1.5, 4.5, 7.5, 10.5, 13.5, 16.5 and 19.5 m from the western end, soil samples were collected from the depth of 45 cm using a 50 cm long, thin steel pipe with an inner diameter of 2.7 cm at the tip and 3.0 cm along the rest of the pipe. At each point, soil samples were collected three times and divided them into five layers (0-5, 10-15, 20-25, 30-35 and 40-45 cm from soil surface); each layer was then collected in a separate plastic bag. These samples were transferred to a polyvinyl chloride container, saturated from the bottom with water taken from the main irrigation channel (EC value: 0.45 dSm^{-1}) and absorbed with an unglazed cup to measure the EC value. Soil samples were collected from the depth of 1.0 m in each line with a hand auger. Measurement of $EC_{1:5}$ values (1 part soil with 5 parts water) and screening tests were performed with these samples.

RESULTS AND DISCUSSION

Cotton growth and EC in the farmland

Along the A Line, 40 m from the road where the growth was bad (Fig. 3), there were sporadic bare areas on the ground and the heights of cotton flowers were uneven. In contrast, along the B Line, 12 m from the road side where the growth was relatively even, there were no bare areas on the ground and the plant heights were comparatively even, albeit with differences of approximately 10 cm. Cotton is a salt-tolerant crop, comparable to beet and alfalfa, and capable of producing a bumper harvest up to an EC value of 8 dSm^{-1}.

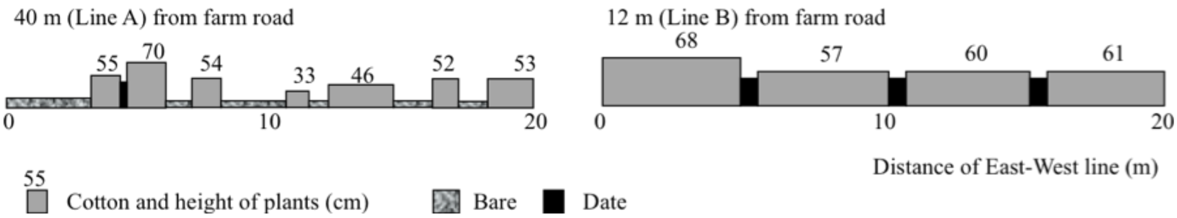

Fig. 3 Growth situation of cotton on each transect line

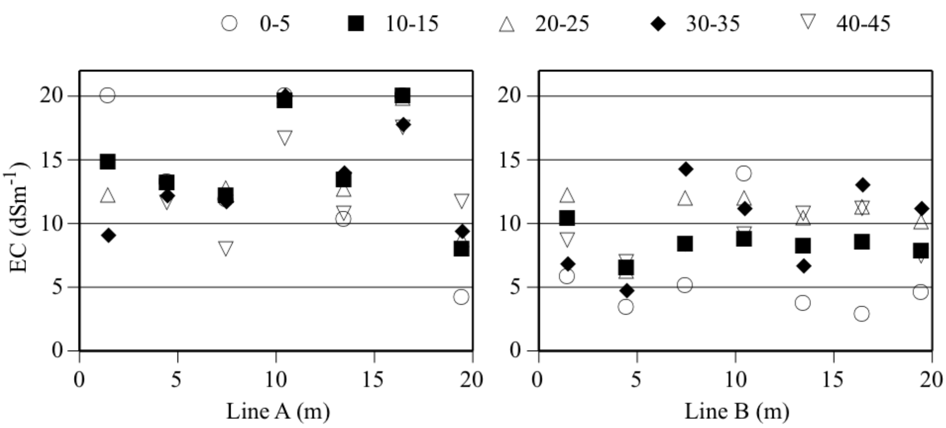

Fig. 4 EC of soil saturation extracts at each depth on farmland

Figure 4 shows the EC values along the A Line in parallel with the heights of cotton. At some points, the EC value exceeded 20 dSm^{-1}, which is the measurement limit of the EC metre used. In such cases, the EC value was recorded uniformly as 20 dSm^{-1} on the figure. In the bare areas, in particular, the EC value of shallow parts exceeded 20 dSm^{-1}.

With the exception of the easternmost point, the EC value exceeded the threshold value for survival at all points and depths along the A Line. Besides, at most points, the shallower the depth, the higher the EC value tended to be, thus indicating an accumulation of salt near the ground surface due to evaporation. On the other hand, along the B Line where the growth of cotton was relatively even, the EC values fluctuated considerably even at the same point depending on the depth. However, the EC value never exceeded 15 dSm^{-1}. Furthermore, with the exception of one point, the EC value of the 0-5 cm layer was below the threshold value of 8 dSm^{-1}; however, at most points, the EC value of the 10-15 cm layer was in the vicinity of the threshold value. Therefore, the deeper the depth, the higher the EC value tended to be (Fig. 4). This suggests that unlike the A Line, the influence of eluviation by irrigation water was greater than that of salt accumulation caused by soil surface evaporation in the B Line.

Because EC is influenced by grain size composition in soil deeper than the target layer, we could not find a tendency in the relationship of the EC value and the percentage of a specific grain size ($<3.8 \times 10^{-5}$ m). However, in the relationship between the EC value of the 0-10 cm layer and the relative elevation of the ground on each sampling point, the $EC_{1:5}$ value increased as the relative elevation increased ($P<0.05$, Fig. 5). From this result, since the dissolved matters move with soil moisture by a capillary power with aridity, saline matters accumulation were estimated in the higher elevation point where is susceptible to such effect.

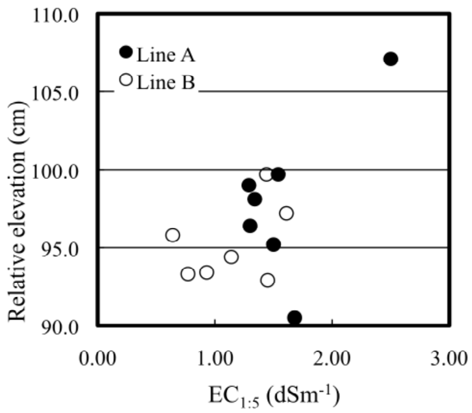

Fig. 5 Relationship of $EC_{1:5}$ and relative elevation of the farmland

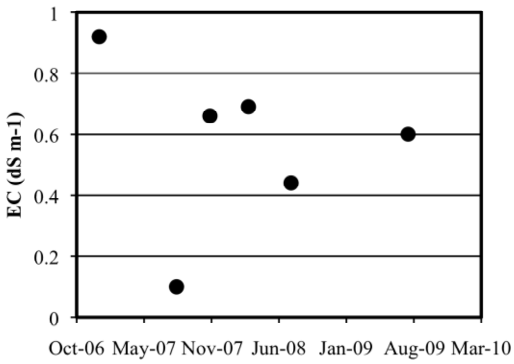

Fig. 6 Changes of EC in irrigation water

Table 1 Water quality of groundwater (Aug 2006)

No.	EC (dSm^{-1})	Cation (meq L^{-1})			Type
		Na^+	Ca^{2+}	Mg^{2+}	
1	4.6	16.0	13.7	15.1	Shallow groundwater (<4.0 m)
2	1.6	5.2	3.7	4.6	
3	2.2	6.4	7.9	9.2	
4	2.0	8.6	2.0	2.0	Well water (<30 m)
5	1.4	4.4	3.9	4.1	
6	2.6	10.8	4.2	7.4	
7	5.1	17.9	11.0	14.1	
8	4.0	12.3	12.9	14.8	
9	3.3	8.7	11.3	15.0	
10	0.6	2.9	1.4	0.0	Well water (120 m)

Water quality in the area

The EC value of irrigation water changes seasonally, and it ranged from 0.4 to 0.7 dSm^{-1} in this area (Fig. 6). According to the standard of United States Department of Agriculture (USDA) (Soil Survey Division Staff, 1993), this value shows an intermediate salt density disorder. The EC values of the groundwater were basically more than 2.0 dSm^{-1} in our research. This result is appropriate because Chen, W. et al. (2010) shows that the salinity levels of most of the shallow groundwater sources in Xinjiang are greater than 2.0 dSm^{-1}. Dissolved cations are shown in Table 1. It shows Na^{+} value is higher at the time of EC is lower, and Mg^{2+} is higher as to be high value of EC. When the EC value of groundwater is compared, the tendency is for the EC value to be higher in the shallow groundwater of a field and to be lower in a deeper well. The influence of the leaching effect by irrigation is the likely cause that EC is higher in shallow groundwater.

Changing of groundwater level

In this area, it is assumed that a groundwater level of more than –2.0 m carry a high risk of soil salinization. The change of groundwater level in research target farmland is shown in Fig. 7.

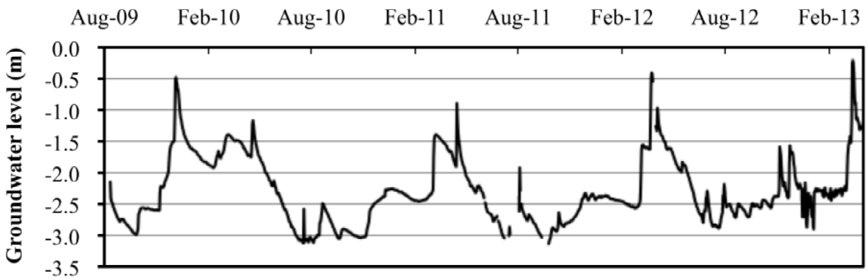

Fig. 7 Change of groundwater level in farmland

It shows groundwater level is higher in the winter and early spring and sufficiently lower in summer. Certainly, groundwater level is higher in the planting period (March to early April), but it is not high enough to be a problem during the cotton growing season.

Why does unevenness of soil salinization occur?

In the case wherein irrigation water was very saline, soil salinization may have occurred due to the salinity being supplied to the field by irrigation water. However, the EC of irrigation water was much lower than that of the groundwater in this study. This suggests that irrigation water is not a direct factor in soil salinization.

According to the USDA standard, the EC value of the irrigation water can be classified as causing moderate salinity damage. Nevertheless, when compared with the EC value and positive ions of shallow underground water, the effects of leaching are evident. This implies that the supply of salts by the irrigation water was not directly connected with salt accumulation. Saline in the soil of the farmland migrates by capillary attraction. In particular, it is believed that the presence of soil stratum containing clay beneath the A_p layer contributes to the maintenance of dampness in the soil, thereby promoting capillary attraction.

When the groundwater level is sufficiently deep, the supply of salts and water from beneath is scarce. However, in this region, irrigation and the thawing of ice in the soil, especially in early spring, causes the groundwater level to rise. Moreover, soil moisture is kept in the soil layer containing clay. In other words, the rise of shallow groundwater supplies the soil with saline from beneath in the annual groundwater fluctuation. This should be a major factor causing soil salinization, as the capillary action of the soil attracts the salts to the surface.

As for the unevenness of cotton growth that occurs in the same farmland, it was considered a waterlogging by inequality of ground surface during the planting period, partial difference of soil structure (soil layer including large amount of clay exists in comparatively shallow depth) and deviation in fertilizer application could be the factors causing the same.

CONCLUSION

The influence of soil salinization on cotton growth in an arid area was observed. Based on the results, in the bare areas, the EC of soil saturate extract exceeded the threshold value (8 dSm^{-1}) for survival at all points and depths. In the area where the growth of cotton was relatively even, the EC values did not exceed the threshold value in 0–5 cm depth. In other words, it is clear that saline accumulation influences cotton growth. On the other hand, it was suggested that the causes of unevenness of soil salinization in the same farmland are soil composition (e.g. clay content) and microrelief (land elevation) on the farmland. Moreover, irrigation water was not a direct factor in soil salinization.

It is thought that soil improvement and the introduction of under-drainage in farmland would be an effective solution for the problem of soil salinization, but this is difficult when cost is considered. For realistic correspondence, it was suggested that crops are grown on furrow. This way should make saline matters beneath the plants move to the ridge direction. It is necessary to verify this hypothesis by further experiments.

ACKNOWLEDGEMENTS

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