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Research Article

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The effect of irrigation amount on soil salinity and the yield of drip irrigated cotton in saline-alkaline soils

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ABSTRACT

In this study, test-pit experiments were performed to investigate the effects of drip irrigation under mulch on the improvement of saline-alkaline soil and cotton yield. The effects of irrigation amount on the distribution and changing characteristics of salts in the 0-100 cm soil layer of drip irrigated cotton fields were evaluated, and the responses of single boll weight, seed cotton yield, lint cotton yield, and lint percentage were analyzed. The results showed that the salt leaching effect was bad with irrigation amount of 400 mm and good with amount of 525-600 mm, and 675 mm of irrigation amount would cause waste in water resource. Non-linear models were developed among seed cotton yield, lint cotton yield, water utilization efficiency (WUE) and irrigation amount, and the optimal irrigation amount of 475.00-564.29 mm was obtained based on the models. Taken together, it was believed that when the initial soil salt content was 2.55%, the suitable irrigation amount for cottons with drip irrigation under mulch in saline-alkaline soils was 525.00-564.29 mm. The results from this study are expected to provide support in raising the WUE of drip irrigation under mulch and in the exploitation and utilization of saline-alkaline soils.

Keywords: Saline-alkaline soil, drip irrigation under mulch, irrigation amount, soil salinity, cotton yield.

INTRODUCTION

As an extensively distributed soil type, saline-alkaline soil is an important part of land resource. Currently, there are about 9.55×10^8 hm^2 (or 25% of the continental area) of saline-alkaline soil in the world [1] and about 0.6×10^8 hm^2 in China [2]. Saline-alkaline soils have potential development value and multiple purposes. In China, agricultural biological measures were mainly used to improve saline-alkaline soils in the 1950s, water was used in the 1960s, and comprehensive measures were employed from the 1970s to present [3]. Xinjiang is located in the inland arid regions with scarce precipitation and strong evaporation. Saline-alkaline soils are extensively distributed there and are expanding [4-5]. Among the 4.0784×10^6 hm^2 cultivated land, 1.2288×10^6 hm^2 (30.13% of cultivated land and 63.2% of fields with low yield) is harmed by salinization of various degrees. Improving and utilizing these land resources is an important part of eco-oasis expansion and sustainable agriculture [6]. In 1996, Xinjiang Production and Construction Corps (XPCC) successfully applied the drip irrigation under mulch technology in saline-alkaline soils and then as an advanced water-saving technology, drip irrigation under mulch has been quickly and extensively promoted and applied by the Corps [7]. Currently, the land area with drip irrigation under mulch is already over 1.33×10^6 hm^2 in Xinjiang [7] which now has the largest field area with drip irrigation under mulch applied in China and even in the world [8].

The rapid promotion and application of the drip irrigation technology has caught attentions of many experts and scientists who began to carry out research in their respective study areas on the effects of irrigation amount on cotton with drip irrigation under mulch. Wang [8] investigated the effects of irrigation amount and irrigation times during the key growth stages on the growth, yield and water utilization efficiency (WUE) of cotton. Lei [9] found that the

irrigation amount of 1760 m^3/hm^2 could bring high yield and WUE of cotton with drip irrigation under mulch. Hu [10] proposed a soil water management scheme for cotton with drip irrigation under mulch. Cai [11] found that water consumption for the whole growth period of cotton with drip irrigation under mulch should be 345-380 mm. Sun [12] reported that a suitable irrigation period for drip irrigation under mulch was 10 d with irrigation amount of 65 mm each time. Gong [13] demonstrated that an irrigation amount of 3900 m^3/hm^2 and an irrigation frequency of 5-7 d were appropriate. And Yang [14] suggested that 12-16 times of irrigation with an amount of 3750-4500 m^3/hm^2 each time was suitable for cotton with drip irrigation under mulch in south Xinjiang.

Drip irrigation under mulch can provide effective means for the exploitation and utilization of saline-alkaline soils in arid and semi-arid regions and is widely applied in Xinjiang. However, in current production practice, the main measures used to control salts in cotton fields with drip irrigation under mulch are salt-suppressing irrigation in winter, salt-suppressing irrigation in spring and irrigation with large amount of water, which wastes water resource and may cause deep percolation and rise of groundwater table, consequently soil salinization. However, if irrigation is not enough and salts are not leached to deeper layers, salts will accumulate around the taproot system of crops, thus affecting the normal growth of crops. Therefore, to investigate the effects of irrigation amount on soil salinity and the yield of cotton with drip irrigation under mulch in saline-alkaline soils and to find out the suitable irrigation amount for cotton with drip irrigation under mulch in saline-alkaline soils can help to raise WUE and provide theoretical basis for the development and utilization of saline-alkaline soils.

EXPERIMENTAL SECTION

The Outline of Study Field

The experiment was conducted in the key laboratory of Modern Water-saving Irrigation Crops of Shihezi University with test-pits from April to October in 2012. The experimental site (85°59′47" E, 44°19′28" N) is located in the second company of the agricultural experiment station of Shihezi University in the western suburbs of Shihezi City in Xinjiang. The site is 412 m a.s.l. with an average ground slope of 6 ‰ and a temperate continental climate. The length, width and depth of the test pits are 3 m, 2 m and 2 m, respectively. The soil used is a light loam with an initial salt content of 2.55%. Drip irrigation under mulch was employed in the experiment and the planting pattern (30+60+30 cm) is shown in Fig.1.

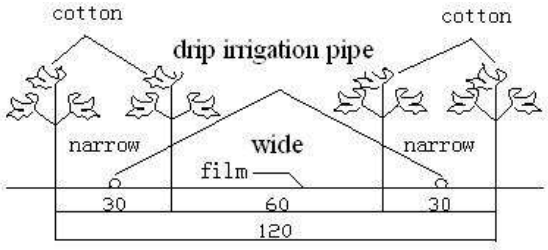

Fig. 1 Schematic description of the planting pattern under drip irrigation (unit: cm)

Experimental Design and Treatment

Four treatments with irrigation amount of 450 mm, 525 mm, 600 mm and 675 mm were set up with a total of 10 irrigation times and three replicates for each treatment. Soil salt content was determined using a portable DDB-2 digital conductivity meter on soil samples taken before sowing, after harvest, or before and after each irrigation using a soil/water ratio of 1/5. The soil samples were taken from the narrow rows and wide rows and around cotton or horizontally at 5 cm, 20 cm, and 45 cm away from the irrigation pipes and from the layers of 0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm. Soil salt content was calculated using the conductivity of soil solution based on the following relationship:

$$y = 0.00005x\text{-}0.0003 \quad R^2 = 0.9795 \tag{1}$$

where y is soil salt content (%), x is conductivity (10^{-2} ms/cm), and R is correlation coefficient.

RESULTS AND DISCUSSION

The Effects of Irrigation Amount on Soil Salinity of Cotton with Drip Irrigation under Mulch

With drip irrigation under mulch in saline-alkaline soils, the migration of soil salts generally includes the following two important processes [2]: the first is that during irrigation, the soil salts migrate with irrigation water away from around the emitters in all directions, and during this process, salts in the surface soil are leached; the second is that when

irrigation stops and there is no more water going down, soil salts migrate with the redistribution of water which is affected by soil moisture gradient, plant transpiration and evaporation of the soil surface. Just because of the water and salt migration rule of "salt goes with water and stops without water" [4], different irrigation amounts will surely cause soil salt changes during the growth period of cotton. To evaluate the effects of irrigation amount on soil salt changes, soil salt content during the main cotton growth stages of bud stage, blossing and boll-forming stages, and boll-opening stage is listed in Table 1. As the taproot system of cotton with drip irrigation under mulch is mainly distributed in the 0-60 cm soil layer, only the salt content in the 0-100 cm soil layer was discussed in this study.

Table 1 Soil salt content during the bud stage, blossing and boll-forming stages, and boll-opening stage of cotton with different irrigation amounts

Irrigation amount (mm)		Bud stage				Blossing and boll-forming stage				Boll-opening stage			
		450	525	600	675	450	525	600	675	450	525	600	675
Soil layer (cm)	0-10	1.52	1.42	0.31	0.26	1.73	2.24	0.6	0.32	0.9	2.75	0.19	0.21
	10-20	1.46	1.32	0.96	0.69	0.68	0.36	0.67	0.68	1.45	1.35	0.91	0.56
	20-40	1.47	1.34	1.58	0.58	0.74	1.07	0.95	0.58	2.1	1.81	1.17	1.17
	40-60	1.68	1.23	1.49	1.15	1.21	1.18	1.34	1.16	2.24	1.72	1.39	1.26
	60-80	2.61	1.43	1.66	1.05	1.71	1.31	1.87	0.34	2.39	1.99	1.65	1.01
	80-100	3.03	1.68	1.64	0.89	1.88	1.6	1.76	0.59	2.5	2.06	1.74	1

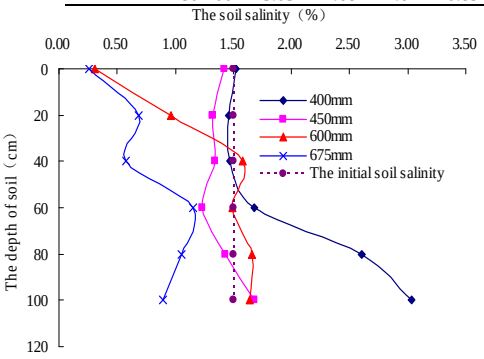

Fig. 2 Soil salt content in the bud stage

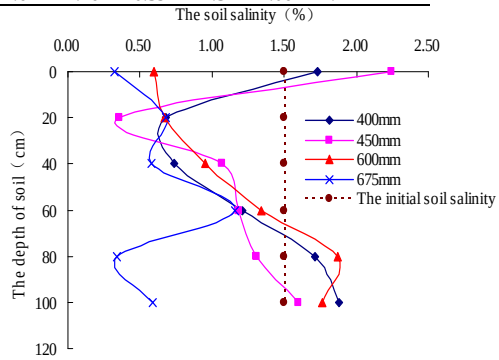

Fig. 3 Soil salt content in the blossing and boll-opening stage

Table 2 The desalination and salt accumulation zones in the 0-100 cm soil layer with different irrigation amounts (unit: cm)

Irrigation amount (mm)	Bud stage		Blossing and boll-forming stages		Boll-opening stage	
	Desalination zone	Salt accumulation zone	Desalination zone	Salt accumulation zone	Desalination zone	Salt accumulation zone
450	10-50	0-10 and 50-100	5-70	0-5 and 70-100	0-20	20-100
525	0-85	85-100	10-95	0-10 and 95-100	15-30	0-15 and 30-100
600	0-35	35-100	0-65	65-100	0-70	70-100
675	0-100		0-100		0-100	

Table 3 Single boll weight, seed cotton yield, lint cotton yield, lint percentage and WUE when irrigation amount was different

Irrigation amount (m^3/hm^2)	Single boll weight (g)	Seed cotton yield (kg/hm^2)	Lint cotton yield (kg/hm^2)	Lint percentage (%)	WUE (kg/m^3)
450	5.23	3975	1680.63	42.28	0.88
525	5.34	4830	2065.79	42.77	0.92
600	5.21	4502	1919.20	42.63	0.75
675	5.07	4107	1745.89	42.51	0.61

Note: Lint cotton yield=Seed cotton yiels×Lint percentage; WUE=Seed cotton yield/Irrigation amount

As salt content of the saline-alkaline soil in the cotton seedling stage was about 2.60%, much higher than the salt tolerance (0.5%) of cotton in Xinjiang, the field was irrigated with large amount of water before the irrigation in bud stage so that salts were suppressed and the salt content in root zone dropped rapidly. The salt content was determined to be about 1.5% which was taken as the initial salt content of the soil. The zone with salt content lower than the initial salt content was called desalination zone while that with salt content higher than the initial salt content was called salt accumulation zone. To investigate the effects of irrigation amount on the desalination zones and salt accumulation zones in the growth stages of cotton with drip irrigation under mulch, soil salt contents during the main growth stages of cotton were compared with soil initial salt content and results are presented in Figs. 2-4.

From Figs. 2-4, we can get the desalination zones and salt accumulation zones during the main growth stages of cotton with drip irrigation under mulch when irrigation amount was different as shown in Table 2.

As can be seen from Table 2, when irrigation amount was 675 mm, the 0-100 cm soil layer was in a state of desalination during the bud stage, blossing and boll-forming stages and boll-opening stage of cotton. As the taproot system of cotton with drip irrigation under mulch was in the 0-60 cm soil layer, water was wasted. During the bud stage, soil salts were

leached to over 60 cm below surface with the irrigation amount of 525 mm. During the blossing and boll-forming stages, soil salts were leached to over 60 cm below surface with the irrigation amount of 450, 525, or 600 mm. During the boll-opening stage, salts were leached over 60 cm below surface with the irrigation amount of 600 mm. Taken together, an irrigation amount of 525-600 mm has a good salt-leaching effect.

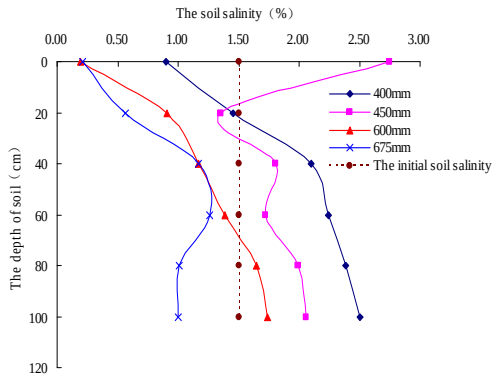

Fig. 4 Soil salt content in the boll-opening stage

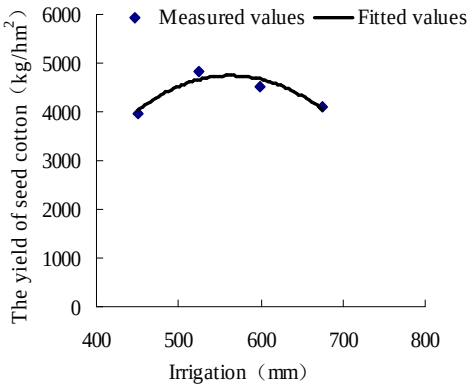

Fig. 5 The fitted curve between irrigation amount and seed cotton yield

The effects of irrigation amount on the yield of cotton with drip irrigation under mulch.

The goal of crop production is to obtain a yield as high as possible with a reasonable irrigation mode and using water resource as little as possible. Cotton yield is reflected by indexes such as single boll weight, seed cotton yield, lint cotton yield, lint percentage, and WUE. Different irrigation amounts can directly affect the growth and development of cotton and lead to different cotton yields. Table 3 shows the single boll weight, seed cotton yield, lint cotton yield, lint percentage, and WUE when irrigation amount was different.

As can be seen from Table 3, when irrigation amount was 525 mm, the single boll weight, seed cotton yield, lint cotton yield, lint percentage and WUE of cotton were high.

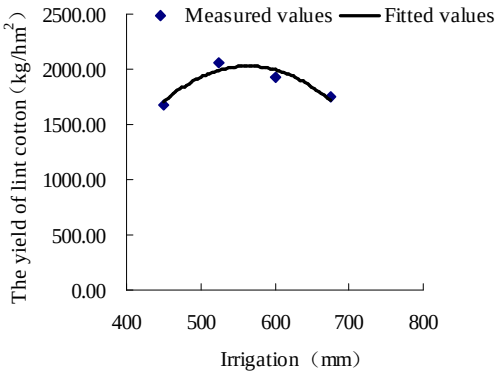

Fig. 6 The fitted curve between irrigation amount and lint cotton yield

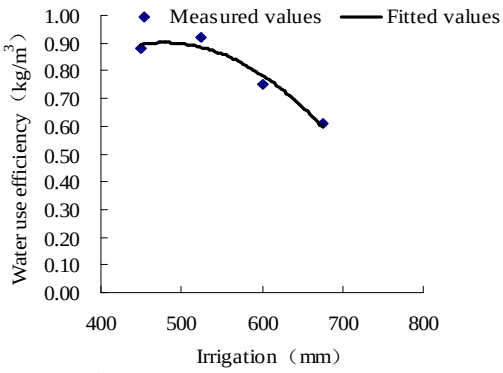

Fig. 7 The fitted curve between irrigation amount and WUE

Non-linear models depicting the relationships between seed cotton yield, lint cotton yield and WUE and irrigation amount were developed based on the measured values (Figs. 5-7) and data fitting:

$$Y_s = -0.0556W^2 + 62.591W - 12885 \quad R^2 = 0.8626 \tag{2}$$

$$Y_l = -0.0248W^2 + 27.989W - 5863.1 \quad R^2 = 0.8596 \tag{3}$$

$$WUE = -8\times10^{-6}W^2 + 0.0076W - 0.9189 \quad R^2 = 0.9544 \tag{4}$$

where Y_s is seed cotton yield (kg/hm^2), Y_l is lint cotton yield (kg/hm^2), W is irrigation amount (mm), and WUE is water use efficiency (kg/m^3).

Take the derivative of the above three functions and let:

$$Y_s' = -0.1112W + 62.591 = 0 \tag{5}$$

$$Y_l' = -0.0496W + 27.989 = 0 \tag{6}$$

$$WUE' = -16\times10^{-6}W + 0.0076 = 0 \quad (7)$$

Solve equation (5) and we get W=562.87 mm. Input this value of W in equation (2) and we get the maximum seed cotton yield: Y_s=4729.70 kg/hm^2.

Solve equation (6) and we get W=564.29 mm. Input this value of W in equation (3) and we get the maximum lint cotton yield: Y_l=2033.92 kg/hm^2.

Solve equation (7) and we get W=475.00 mm. Input this value of W in equation (4) and we get the maximum WUE: WUE=0.89 kg/m^3.

Taken together the seed cotton yield, lint cotton yield and WUE, the best irrigation amount is 475.00 mm-564.29 mm. When the good irrigation amount of 525.00 mm-600.00 mm for salt leaching is also taken into account, it is concluded that when the initial soil salt content is 2.55%, the irrigation amount suitable for cotton with drip irrigation under mulch in saline-alkaline soils is 525.00-564.29 mm.

CONCLUSION

Irrigation amount has an important effect on soil salt distribution in the 0-100 cm soil layer in cotton fields with drip irrigation under mulch. When irrigation amount is 400 mm, the salt-leaching effect is bad. When irrigation amount is 525-600 mm, salt-leaching effect is good. An irrigation amount of 675 mm will cause waste in water resource. Non-linear models among seed cotton yield, lint cotton yield, and WUE and irrigation amount show that the optimal irrigation amount is 475.00-564.29 mm. Taken together seed cotton yield, lint cotton yield, WUE and salt-leaching effect, an irrigation amount of 525.00-564.29 mm is suitable for cotton with drip irrigation under mulch when soil initial salt content is 2.55%.

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