EFFECTS OF INTERCROPPING DIFFERENT HALOPHYTES IN BARE STRIPS ON SOIL WATER CONTENT, SALT ACCUMULATION, AND COTTON (*GOSSYPIUM HIRSUTUM*) YIELDS IN MULCHED DRIP IRRIGATION

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(Received 18th Mar 2020; accepted 9th Jul 2020)

Abstract. Mulched drip irrigation is an important water-saving irrigation method in Xinjiang, China. Three different halophytes (*Cuminum cyminum* L., *Suaeda salsa*, and *Medicago sativa* L.) were intercropped in bare soil strips between rows of plastic film in mulched drip irrigation on cotton fields to assess the distribution of soil salt. The control group (CK) was not intercropped with halophytes. The effects of the treatments on soil evaporation, accumulated soil salinity, and cotton yield were investigated. The results indicated that compared to the CK, soil evaporation was reduced by 11.4%-24.9% and 5.5%-29.2% in 2014 and 2015, respectively. Intercropping halophytes decreased the soil salinity accumulation rate by 50%-134% and 74%-125% compared to the CK in the 0-40 cm and 0-100 cm deep soil layers in both years of total area. The accumulation rate of the soil sodium ions decreased by 29%-138% and 17%-148% in the 0-40 cm and 0-100 cm deep soil layers compared to the CK and the accumulation rate was lowest for intercropping *Suaeda salsa*. Intercropping halophytes had little effect on the cotton yield but slightly decreased the water use efficiency (WUE) of the cotton plant. Intercropping halophytes represents a new method for improving saline-alkaline soils.
Keywords: *soil evaporation, soil salinity, soil sodium ions, harvest index, water use efficiency*

Introduction

The shortage of water resources and soil salinization are important factors restricting the development of agricultural production in Xinjiang, China (Li et al., 2016). Therefore, it is very important to improve the utilization efficiency of water and reduce secondary soil salinization caused by excessive evaporation (Ji and Unger, 2001). It has been shown that increasing the surface coverage and adopting drip irrigation under mulch noticeably reduced secondary salinization (Prueger et al., 1996). Mulched drip irrigation is an irrigation method that combines drip irrigation and plastic film and this method is widely used in arid and semi-arid regions of China (Li et al., 2016). Studies have shown that drip irrigation provides accurate control over the amount of water, reduces deep seepage, and decreases the damage due to salinity in the root layer of the crop (Wang et al., 2014). Drip irrigation can cause salt redistribution in the soil and results in a desalination zone under the plastic film and a salt accumulation zone in the bare strips between the two rows of plastic film. The accumulation of salt in the bare-soil strips produces a "w-shaped" distribution of salt in the fields that influences salt leaching in winter, irrigation efficiency, as well as the growth and yield of the subsequent crop (Qiao et al., 2011). Research has demonstrated that drip irrigation results in the formation of a low-salt zone in the root area after drip irrigation has been used in the cotton (*Gossypium hirsutum*) growth periods; however, salt accumulation is extensive in the bare strips where no plastic film covers the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1804_59235937

soil and where salt accumulates at the wetted edge of the drip irrigation zone (Zhang et al., 2008). The salt will accumulate in cotton fields when drip irrigation is used for long periods (Zhang et al., 2008). The development of a suitable method to control soil evaporation in the bare strips between the plastic film rows has been challenging (Tan et al., 2017). Therefore, it is of great importance to solve the problem of secondary salinization of the soil and to seek a sustainable method suitable for mulched drip irrigation systems.

Halophytes take up and accumulate high concentrations of salt in the aboveground tissues and saline soils can be improved by harvesting the plants (Manousaki and Kalogerakis, 2011; Panta et al., 2014). This process of reducing the amount of salt in the soil is called a salt pump (Sagers et al., 2017). The salt content of the soil layer in the 0-10 cm layer was reduced on average by 38.5% by planting halophytes (Zhao et al., 2003; Shaygan et al., 2017). In addition, the organic matter content of the surface soil is increased (Xiao et al., 2012). Can salinity be reduced by intercropping halophytes, and how does intercropping halophytes affect crop yields? The growth and yields of tomatoes (*Solanum lycopersicum*) were increased by planting the halophyte *Portulaca oleracea* L. (Zuccarini, 2008). The Na^+ concentration was reduced and the quality of tomatoes under salt-stress was increased by intercropping *Salsola soda* L. (Graifenberg et al., 2003; Zhang et al., 2019). The yield of watermelon (*Citrullus lanatus*) was increased by intercropping orache (Simpson et al., 2013). Saltwort intercropped with tomato was able to reduce the Na^+ concentration in both the foliage and the growing medium (Albaho and Green, 2000). Intercropping salt-tolerant plants decreased the accumulation of sodium in olive trees in an olive-grass system (Chehab et al., 2018). These previous studies have shown that intercropping halophytes could promote the absorption of soil salt and increase crop yield. The halophytes of *Cuminum cyminum* L., *Suaeda salsa*, and *Medicago sativa* L. are common plants in Xinjiang. Therefore, in this study, we chose these three halophytes for intercropping on bare soil strips between rows of plastic films in light and medium saline-alkaline soils. And the objective of this study was to investigate the effect of intercropping halophytes on soil evaporation, soil desalination, and cotton yield.

Materials and methods

Experimental site description

The field experiment was conducted at the Bazhou Irrigation Experimental Station (41°35′N, 86°09′E, 901 m a.s.l.) in the Tarim Basin of Xinjiang in northwestern China (*Figure 1*) during 2014 and 2015 (Li et al., 2016). The region is an area of irrigated agriculture and has a continental desert climate with long-term annual precipitation of 58 mm and average potential evaporation of 2788 mm (Wang et al., 2014; Li et al., 2016). The soil is a sandy loam according to the United States Department of Agriculture soil taxonomy, and the particle size distribution is 3.26% for clay, 59.96% for silt, and 36.78% for sand.

Experimental design

The planting model and drip line arrangement in the experimental field consisted of one row of film, two drip lines, and four rows of cotton (*Figure 2*). The length and width of the experimental field was 7.5 m×7.0 m, and the row spacing of the cotton was 10 cm.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1804_59235937

Four rows of cotton were covered by white plastic film and were irrigated with two drip lines with emitter intervals of 30 cm and a discharge rate of 2.2 L·h^{-1}. The irrigation amounts during the growth period were 525 mm and 450 mm in 2014 and 2015, respectively. The drip irrigation amount in the 2014 season was higher than that in the 2015 season because the precipitation was 23.3 mm in the 2014 season and 60.8 mm in the 2015 season. The irrigation was adjusted appropriately during the season to minimize the water difference between the seasons. The cotton was sown on May 3, 2014 and April 23, 2015 and the halophytes *Cuminum cyminum* L. (IC), *Suaeda salsa* (IS), and *Medicago sativa* L. (IM) were sown in bare strips between the rows of plastic film in each treatment on May 10, 2014 and April 30, 2015 (*Figure 3*). The density of the halophyte seeds and cotton seeds were 600 seeds/m^2 and 40 seeds/m^2, respectively. The management of the cotton fields was similar to that of local farmers (Li et al., 2016). No intercropping was done in the control group (CK). All treatments were conducted in triplicate.

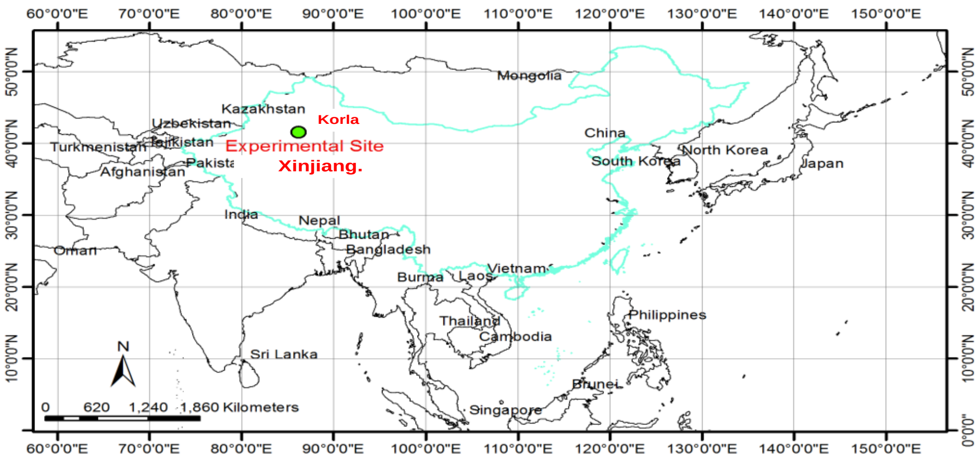

Figure 1. *Location of the experimental site in Korla City, Xinjiang, northwestern China*

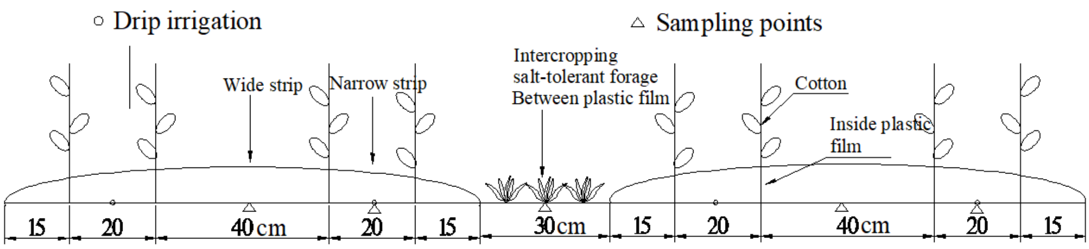

Figure 2. *Field experiment layout*

Data collection

Meteorological data

The meteorological data included precipitation, air temperature, relative humidity, and wind speed at a height of 2 m; the data were collected with a Davis wireless Vantage Pro2 weather station (Davis Instruments, California, USA), which was installed in the experimental field about 30 m away. The evapotranspiration (ET_0) during the 2014 and 2015 seasons (*Figure 4*) was calculated using the Penman-Monteith equation.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Figure 3. *Field experiments of non-intercropping halophytes and intercropping halophytes in the bare strips*

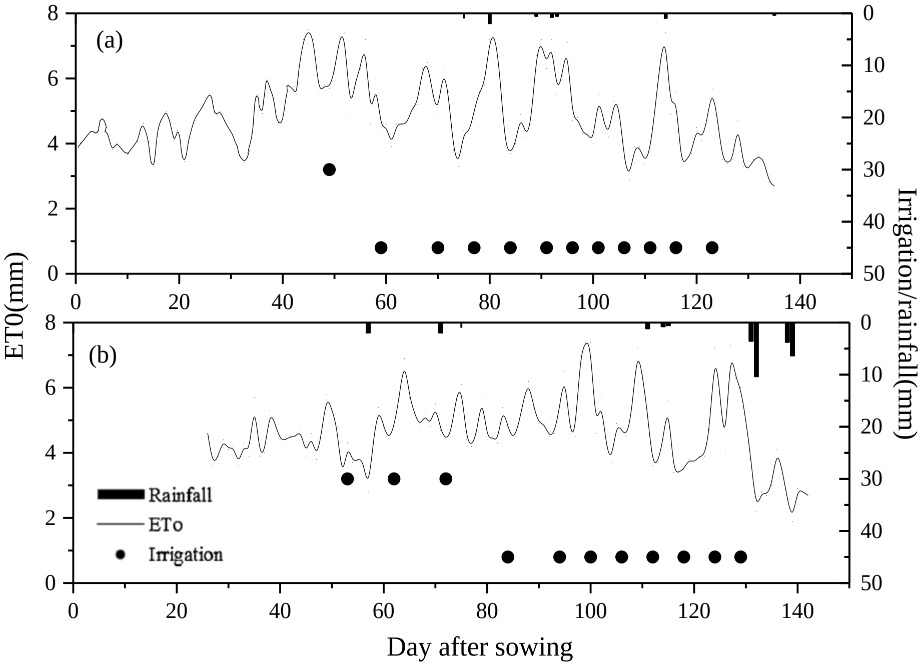

Figure 4. *Daily reference crop evapotranspiration (ET_0), rainfall, and irrigation at the experimental site during the 2014 and 2015 seasons*

Canopy cover and soil evaporation measurements

The canopy cover of the halophytes was measured using a plant canopy analyzer on July 26, 2014 and August 7, 2015. The soil evaporation of all treatments was monitored daily from July 19, 2014 to July 25, 2014 and from July 31, 2015 to August 6, 2015 at 20:00 with microlysimeters (Lage et al., 2003; Uclés et al., 2013) (13 cm diameter, 20 cm length, and 1.8 mm wall thickness), which were installed in the bare strips between the rows of plastic film.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Soil water and soil salt

Soil samples were collected from the 0 to 40 cm soil layer at 10 cm intervals and from the 40 to 100 cm soil layer at 20 cm intervals using a 3.0 cm diameter auger to determine the water content, salt content and sodium ion content of the soil in the middle of the wide, narrow, and bare strips. The soil samples were collected prior to irrigation in the main growth stages of cotton (seedling, squaring, and flower-boll stage) and after harvest. The date of soil sample collection after harvest were Sep. 13, 2014 and Sep. 20, 2015. The auger holes were refilled with soil after collecting the samples to minimize the experimental error. The gravimetric soil water content (SWC) was determined by weighing the soil samples, followed by oven-drying at 105 ±2 ℃ for 24 h and reweighing. The soil volumetric water content was obtained by multiplying the mass water content with the average bulk density of each soil layer.

The electrical conductivity (EC) was determined using a DDS-307A conductivity meter (INESA, Shanghai, China) at a 1:5 soil to water extract ($EC_{1:5}$) at 25 ℃. The soil salt content was determined by converting the value of $EC_{1:5}$ for each soil sample using a linear relationship ($S=3.946\times EC_{1:5}$; $R^2=0.987$). The sodium ion contents were determined with an ion analyzer of PXSJ-216 (INESA, Shanghai, China) at a 1:5 soil to water extract ($EC_{1:5}$) at 25 ℃.

Yield and biomass measurements

The cotton (seeds and lint) was harvested from a 6.25 m^2 area in each treatment on Sep. 11, 2014 and Sep. 18, 2015. Three cotton plants from every treatment were randomly selected, collected, cut, and oven-dried at 70 ℃ until the weight remained stable to determine the aboveground biomass and harvest index (HI).

Calculations and analysis methods

Evapotranspiration calculation

The ET was calculated based on the water-balance equation:

$$ET = P_r + I + G - R - SI \pm \Delta W \quad \text{(Eq.1)}$$

$$\Delta W = SWS_f - SWS_i \quad \text{(Eq.2)}$$

where P_r is the rainfall (mm); I is the irrigation amount (mm); G is the supplementary amount of groundwater (mm); R is the surface runoff (mm); SI is the deep seepage (mm); ΔW is the change in soil water storage (SWS) in a 1.0-m profile (mm); SWS_f is the soil water storage at harvest and SWS_i is the soil water storage in the initial stage. The supplementary amount of groundwater and the surface runoff could be neglected because of the deep groundwater table (> 5 m) and the use of drip irrigation. Therefore, *Eq. (1)* was simplified in this experiment as follows:

$$ET = P_r + I \pm \Delta W \quad \text{(Eq.3)}$$

Calculation of soil water storage

SWS is defined as the amount of water stored in the soil. It is expressed as:

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$$SWS = \overline{\theta}_{0\sim10cm} \times r_{0\sim10cm} \times 10 + \cdots + \overline{\theta}_{80\sim100cm} \times r_{80\sim100cm} \times 20 \quad \text{(Eq.4)}$$

$$\overline{\theta}_{0\sim10cm} = \frac{2}{7}\theta_{W(0\sim10cm)} + \frac{7}{14}\theta_{N(0\sim10cm)} + \frac{3}{14}\theta_{B(0\sim10cm)} \quad \text{(Eq.5)}$$

$$\overline{\theta}_{80\sim100cm} = \frac{2}{7}\theta_{W(80\sim100cm)} + \frac{7}{14}\theta_{N(80\sim100cm)} + \frac{3}{14}\theta_{B(80\sim100cm)} \quad \text{(Eq.6)}$$

where $\overline{\theta}_{0\text{–}10cm}$ is the average water content in the 0-10 cm soil layer (cm^3 cm^{-3}); $\theta_{B(0\text{-}10cm)}$ and $\theta_{I(0\text{-}10cm)}$ are the actual water contents between the rows of plastic film and under the plastic film in the 0-10 cm soil layer (cm^3 cm^{-3}), respectively. The average soil water content of the other soil layers was determined in the same manner.

Calculation of salt and sodium ion content in the soil

The soil salt content and the accumulation rate of soil salt during both seasons were obtained as follows:

$$s_I = \frac{7}{11} \times s_N + \frac{4}{11} \times s_W \quad \text{(Eq.7)}$$

$$s_Z = \frac{11}{14} \times s_I + \frac{3}{14} \times s_B \quad \text{(Eq.8)}$$

$$D_s = \frac{s_f - s_i}{s_i} \quad \text{(Eq.9)}$$

where s_N, s_W, s_I, and s_B are the differences in the soil salt content in the narrow strips, wide strips, inside the plastic film, and the bare strips in the 40 cm or 100 cm soil profile (g/kg), respectively; s_z is the soil salt content in the entire soil layer; s_f and s_i are the soil salt contents in the entire soil layer at the harvest and late seedling stages, respectively; D_s is the accumulation rate of the soil salt from the late seedling stage to harvest.

The soil sodium ion content and the accumulation rate during both seasons were obtained as follows:

$$i_I = \frac{7}{11} \times i_N + \frac{4}{11} \times i_W \quad \text{(Eq.10)}$$

$$i_Z = \frac{11}{14} \times i_I + \frac{3}{14} \times i_B \quad \text{(Eq.11)}$$

$$D_i = \frac{i_f - i_i}{i_i} \quad \text{(Eq.12)}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1804_59235937

where i_N, i_W, and i_B are the soil sodium contents (Na^+ content in the soil) in the narrow, wide, and bare strips in the 40 cm or 100 cm soil profile (g/kg), respectively; i_z is the soil Na^+ content in the entire soil layer; i_f and i_i are the soil Na^+ contents in the entire soil layer at the harvest and late seedling stages, respectively; D_i is the accumulation rate of the soil sodium ions from the late seedling stage to harvest.

Harvest index

The harvest index (HI) was calculated as follows:

$$HI = \frac{Y}{B} \quad \text{(Eq.13)}$$

where *HI* is the harvest index of the cotton, %; *Y* is the yield (seeds and lint) of the cotton at harvest, kg ha^{-1}; *B* is the biomass of cotton at harvest, kg ha^{-1}.

Water use efficiency calculation

The water use efficiency (WUE) (kg/m^3) for all treatments was calculated as follows (Sun et al., 2012):

$$WUE = \frac{Y}{ET} \quad \text{(Eq.14)}$$

where *Y* is the yield (seeds and lint) of the cotton at harvest and *ET* is the total evapotranspiration (mm) during the entire growing season.

Statistical methods

Analysis of variance (ANOVA) was performed using SPSS 19.0. Multiple comparisons were performed using Duncan's test to determine the mean differences in the average evaporation, SWS, ET, soil salt, and soil sodium ion content, as well as the yield and biomass between different treatments.

Results

Soil evaporation and water balance

The soil evaporation rates of the different halophytes in the bare strips were significantly lower than that of the CK during the observation period in the 2014 and 2015 seasons, except for the IM treatment in 2015 (P<0.05, *Table 1*). The reductions in soil evaporation rates relative to the CK for the three halophyte treatments ranged from 11.4% to 24.9% in 2014 and from 5.5% to 29.2% in 2015. The lowest daily soil evaporation rate occurred in IS in both years. The soil evaporation rate of the IS was 2.71 mm in 2014 and 2.96 mm in 2015; these values were 24.9% and 29.2% lower, respectively than that of the CK. The canopy cover was highest for *Suaeda salsa* due to the vigorous growth and this reduced soil evaporation. The daily soil evaporation of IM was the highest of the treatments at 3.20 mm and 3.95 mm in 2014 and 2015, respectively, because of the low canopy cover of *Medicago sativa* L.

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Table 1. *Canopy cover and daily soil evaporation for the different treatments*

Treatment	2014			2015		
	Cover degree (%)	**Average evaporation (mm day^{-1})**	**Reduction evaporation relative to CK (%)**	**Cover degree (%)**	**Average evaporation (mm day^{-1})**	**Reduction evaporation relative to CK (%)**
IC	59ab	3.17b	12.2	48b	3.37b	19.4
IS	77a	2.71c	24.9	70a	2.96c	29.2
IM	33bc	3.20b	11.4	21bc	3.95a	5.5
CK	0d	3.61a	-	0d	4.18a	-

Notes: Soil evaporation in 2014 and 2015 was measured once a day from 19 July to 25 July and 31 July to 6 August, respectively. Canopy cover was measured at the start and end of the period. The canopy cover value represents the average of two measurements of canopy cover. IC stands for intercropping *Cuminum cyminum L.* in the bare strips between the rows of plastic film, IS stands for *Suaeda salsa*; IM stands for *Medicago sativa L.*, and CK stands for the control group with no intercropping. Means with different lowercase letters in the same column represent significant differences at P<0.05

It has been demonstrated that about 85% of cotton roots occur in the 30-50 cm soil layer under mulched drip irrigation (Kang et al., 2012); therefore, the soil layer of 0-40 cm was considered the main root zone of cotton. The SWS in the 0-40 cm soil layer is shown in *Figure 5*. For the treatment of intercropping halophytes between plastic films, the average SWS in the main root zone in the growth periods decreased 7.7%-18.77% and 5.3%-13.69% during 2014 and 2015, respectively. In contrast, the average SWS in the main root zone for the CK increased 0.26% and 2.53% during 2014 and 2015, respectively. The largest decline in the average SWS (compared to the initial SWS) was observed for *Medicago sativa* L. (18.77% decrease) and *Cuminum cyminum* L. (13.69% decrease) in 2014 and 2015. The average SWS of the main root zone decreased due to intercropping of halophytes because the halophytes consumed soil moisture.

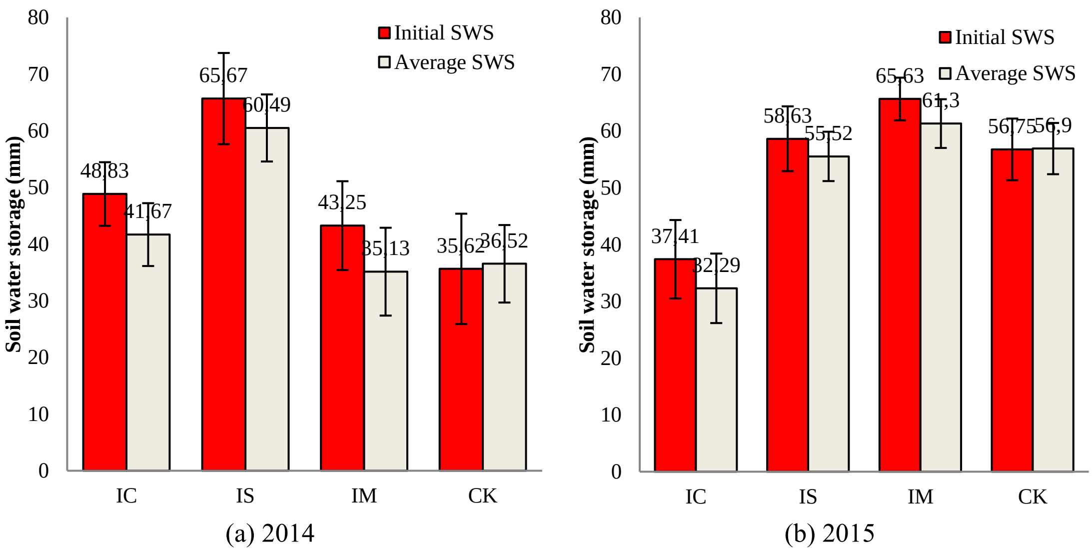

Figure 5. *The initial and average SWS at 40 cm depth for the different treatments in 2014 and 2015. Notes: IC stands for intercropping Cuminum cyminum L. in the bare strips between the rows of plastic film, IS stands for Suaeda salsa; IM stands for Medicago sativa L., and CK stands for the control group with no intercropping. Error bar represents the standard error of the mean (n=3)*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1804_59235937

ET rates differ for different crops (Allen et al., 1998). The ET was determined by calculating the changes in soil water content in the 0~100 cm soil layer at the initial stage and final stage of the experiment (*Table 2*). The initial SWS was significantly different for the treatments due to the spatial variability of the soil water content during the 2014 and 2015 seasons. There were no large precipitation events, and the planned wetting layer was between 45 mm and 50 mm during the drip irrigation; therefore, underground leakage was ignored. The ET increased by 8.54%-18.19% and 3.55%-10.40% in 2014 and 2015, respectively, due to the intercropping of halophytes between the rows of plastic film may consume a part of soil water moisture. The ET of the IS and IC treatments were not significantly different during the 2014 and 2015 seasons, and the ET was highest for the IM.

Table 2. *Water balances for the different treatments in the 100-cm soil profile*

Year	Treatment	Initial SWS (mm)	Final SWS (mm)	Rainfall (mm)	I (mm)	ET
2014	IC	146.90b	106.05a	23.3	525	589.15b
	IS	167.05a	127.96a	23.3	525	587.39b
	IM	150.84b	72.19b	23.3	525	626.95a
	CK	122.99c	127.76a	23.3	525	543.54c
2015	IC	95.49c	97.82b	60.8	450	508.47b
	IS	150.55ab	151.31a	60.8	450	510.04b
	IM	164.1a	132.83a	60.8	450	542.09a
	CK	123.81b	143.56a	60.8	450	491.05c

Notes: IC stands for intercropping *Cuminum cyminum L.* in the bare strips between the rows of plastic film, IS stands for *Suaeda salsa*; IM stands for *Medicago sativa L.*, and CK stands for the control group with no intercropping. Means with different lowercase letters in the same column represent significant differences at $P<0.05$

Changes in the soil salt

High concentrations of soil salt may reduce cotton growth, although cotton is saline tolerant (Zhang et al., 2014). The changes in the soil salinity (*Table 3*) and sodium ions content (*Table 4*) were assessed for the 0-40 cm soil layer of the main root zone and the 0-100 cm soil layer. The accumulation rate of the soil salt content was evaluated by determining the change rate of the soil salt content between the initial and final stages to avoid the influence of the initial salt content on the evaluation of the changes in the soil salt content in different treatments. The salt accumulation was higher between the rows of plastic film than under the plastic film and low salt content was maintained in the root zone of the cotton because the drip irrigation under the plastic film caused leaching, which decreased the salt concentration.

The soil salt accumulation rates of intercropping halophytes in the bare strips were lower than that of the CK in 2014 and 2015. Compared to the CK, the accumulation rates were 50%-134% and 74%-125% lower in the 0-40 cm and 0-100 cm soil layers of the total area, respectively, indicating that the salt accumulation was slowed down by intercropping halophytes in the bare strips between the rows of plastic film. The salt content of the 0-40 cm soil layer was higher than that of the 0-100 cm soil layer, showing that the soil salt accumulated in the upper layer of the soil during the cotton growth. The soil salt accumulation rate was lower in 2015 than in 2014 in the total area

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DOI: http://dx.doi.org/10.15666/aeer/1804_59235937

in the 0-40 cm soil layer and 0-100 cm soil layers. The salt accumulation rate was not different for the different locations (between the plastic film, under the plastic film, and the total area), except for the IM treatment in 2014.

Table 3. *The accumulation rate of the soil salt (s) for the different treatments between the plastic films, under the plastic film, and the total area in the 40 cm and 100 cm soil profiles in 2014 and 2015*

Year	Location	Treatment	0~40cm			0~100cm		
			Initial salinity (g/kg)	Final salinity (g/kg)	D_s/%	Initial salinity (g/kg)	Final salinity (g/kg)	D_s/%
2014	Between plastic film	IC	3.91a	7.71a	97.19	3.2a	5.08a	58.75
		IS	2.19b	4.11b	87.67	1.27b	2.09b	64.57
		IM	4.39a	2.89b	-34.17	2.02ab	2.41b	19.31
		CK	1.99b	7.76a	289.95	1.15b	4.09a	255.65
	Under plastic film	IC	5.92a	8.26a	39.53	4.14a	3.97a	-4.11
		IS	3.99a	4.74b	18.80	2.32a	2.4a	3.45
		IM	4.75a	1.97c	-58.53	2.13ab	1.37b	-35.68
		CK	1.38b	2.84c	105.8	1.33b	2.16a	62.41
	Total area	IC	5.49a	8.14a	48.33	3.94a	4.21a	6.84
		IS	3.60b	4.61b	27.76	2.10b	2.33b	11.39
		IM	4.67ab	2.17b	-53.62	2.11b	1.59b	-24.38
		CK	1.51c	3.89b	157.78	1.29b	2.57b	99.28
2015	Between plastic film	IC	3.42b	4.46b	30.41	1.76a	1.68b	-4.55
		IS	5.5a	3.91b	-28.91	2.09a	1.87b	-10.53
		IM	6.21a	9.97a	60.55	3.4a	4.14a	21.76
		CK	2.98b	8.01a	168.79	1.53a	3.73a	143.79
	Inside plastic film	IC	3.69a	4.81b	30.35	1.51a	1.86b	23.18
		IS	3.67ab	3.3b	-10.08	1.94a	1.66b	-14.43
		IM	5.17a	7.09a	37.14	2.85a	3.18a	11.58
		CK	1.98b	3.02b	52.53	0.96a	1.25b	30.21
	Total area	IC	3.63ab	4.74b	30.36	1.56a	1.82b	16.49
		IS	4.06a	3.43b	-15.54	1.97a	1.71b	-13.55
		IM	5.39a	7.71a	42.91	2.97a	3.39a	14.08
		CK	2.19b	4.09b	86.36	1.08a	1.78b	64.62

Notes: IC stands for intercropping *Cuminum cyminum L.* in the bare strips between the rows of plastic film, IS stands for *Suaeda salsa*; IM stands for *Medicago sativa L.*, and CK stands for the control group with no intercropping. Means with different lowercase letters in the same column represent significant differences at $P<0.05$

Changes in sodium ion content

Sodium ions can damage the crop and destroy the soil structure (Zhang et al., 2016; Li et al., 2019). Sodium ions may have an adverse effect on the growth and development of cotton if the sodium ion content in the soil exceeds the salt tolerance threshold of cotton (Farooq et al., 2019). The sodium ion accumulation rates of all treatments in 2015 were lower than that in 2014 in the 0-40 cm and 0-100 cm soil layers (*Table 4*) because the sodium ions were leached due to precipitation in the late growing stage of the cotton. The average soil sodium ion content was higher in the 0-40 cm soil layer than in the 0-100 cm layer at the harvest stage, showing that the sodium ions accumulated near the surface. The

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DOI: http://dx.doi.org/10.15666/aeer/1804_59235937

soil sodium ion accumulation rates of the treatment intercropping halophytes were 29% to 138% and 17% to 148% lower than that of CK in the 0-40 cm and 0-100 cm soil layers in total area, respectively. Intercropping halophytes in the bare strips between the plastic films reduced the accumulation rate of the soil sodium ions. The accumulation rate of soil sodium ions of the IS was 91% and 139% lower than that of the CK in the 0~40 cm soil layer in the total area, respectively, in 2014 and 2015. In 2014, the IS treatment had the lowest accumulation rate of sodium ions in the 0~40 cm soil layer, followed by the IC treatment and IM treatment. And in 2015, the soil sodium ion accumulation rates in the IS and IM treatments were lower than in 2014, and those of the IC treatment were higher at harvest in 2014. The accumulation rate of the soil sodium ions were lowest for the IS treatment in 2014 and 2015.

Table 4. *The accumulation rate of the soil sodium ion (Na^+) content for the different treatments between the plastic film, under the plastic film, and the total area in the 40 cm and 100 cm soil profiles in 2014 and 2015*

Year	Location	Treatment	0~40cm			0~100cm		
			Initial Na^+ content (g/kg)	Final Na^+ content (g/kg)	D_i/%	Initial Na^+ content (g/kg)	Final Na^+ content (g/kg)	D_i/%
2014	Between plastic film	IC	0.056a	0.138a	144.90	0.029b	0.079a	176.00
		IS	0.075a	0.082b	9.23	0.077a	0.055a	-28.36
		IM	0.039b	0.121a	208.82	0.021b	0.057a	173.91
		CK	0.038b	0.150a	293.94	0.018b	0.056a	206.25
	Under plastic film	IC	0.045a	0.105a	133.33	0.026b	0.066a	147.83
		IS	0.071a	0.104a	17.74	0.046a	0.071a	55.00
		IM	0.045a	0.097a	115.38	0.035ab	0.069a	100.00
		CK	0.024b	0.059a	145.83	0.012b	0.033b	175.00
	Total area	IC	0.047a	0.112a	136.59	0.027b	0.069a	154.27
		IS	0.072a	0.099a	14.29	0.053a	0.068a	28.86
		IM	0.044a	0.102a	134.21	0.032b	0.066a	110.39
		CK	0.027b	0.079a	190.72	0.013c	0.038b	185.48
2015	Between plastic film	IC	0.213a	0.362a	70.26	0.113a	0.221a	95.88
		IS	0.112bc	0.064b	-42.27	0.107a	0.038c	-64.52
		IM	0.164ab	0.309a	88.11	0.136a	0.145b	6.78
		CK	0.034c	0.108b	217.65	0.034b	0.092b	170.59
	Under plastic film	IC	0.146a	0.286a	96.13	0.168a	0.312a	85.65
		IS	0.146a	0.052b	-64.57	0.141b	0.062c	-76.42
		IM	0.201a	0.118b	-41.31	0.199a	0.121b	-67.63
		CK	0.021c	0.049b	133.33	0.023c	0.057c	147.83
	Total area	IC	0.160a	0.302a	88.77	0.156ab	0.293a	87.23
		IS	0.139a	0.055b	-60.72	0.134b	0.057c	-74.36
		IM	0.193a	0.159b	-17.86	0.185a	0.126b	-55.90
		CK	0.024b	0.062b	159.16	0.025c	0.065c	154.37

Notes: IC stands for intercropping *Cuminum cyminum L.* in the bare strips between the rows of plastic film, IS stands for *Suaeda salsa*; IM stands for *Medicago sativa L.*, and CK stands for the control group with no intercropping. Means with different lowercase letters in the same column represent significant differences at P<0.05 level

Aboveground biomass and yield of cotton

There was no significant difference in the yield and biomass between the treatments during the 2014 and 2015 seasons (*Table. 5*). The harvest index (HI) of the treatments

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ranged from 48.77% to 54.33% and 50.94% to 55.07% during the 2014 and 2015 seasons and the HIs of all treatments were lower in 2014 than in 2015. The reason is that the amount of irrigation in the early part of 2014 was higher and the cotton growth was better than in 2015. Compared to the CK, intercropping halophytes reduced the HI of cotton by 4.51%-10.23% and 0.78%-7.5% during the 2014 and 2015 seasons, respectively. The HI of the CK was higher than that of the intercropping halophytes because the low water consumption of the halophyte treatment between the plastic films in the early growth stage did not affect the uptake of nutrients and the halophytes competed with the cotton for soil water content and nutrients in the later growth stage. The WUE was lower in 2014 due to more irrigation. The WUE of the intercropping treatments was 6.41%-10.26% and 1.1%-4.4% lower than that of the CK during 2014 and 2015, respectively. The reason is that the halophytes compete with the cotton for soil moisture and nutrients.

Table 5. *Cotton yield, biomass, harvest index (HI), evapotranspiration (ET), and water-use efficiency (WUE) for different treatments in 2014 and 2015*

Year	Treatment	Yield (kg ha^{-1})	Biomass (kg ha^{-1})	HI (%)	WUE
2014	IC	4102.44a	8121.39a	50.51	0.70
	IS	4301.35a	8819.16a	48.77	0.73
	IM	4513.44a	8669.16a	51.88	0.72
	CK	4243.40a	7800.95a	54.33	0.78
2015	IC	4551.53a	8330.56a	54.64	0.90
	IS	4445.41a	8716.49a	50.94	0.87
	IM	4762.72a	8972.41a	53.16	0.88
	CK	4445.07a	8081.95a	55.07	0.91

Notes: IC stands for intercropping *Cuminum cyminum L.* in the bare strips between the rows of plastic film, IS stands for *Suaeda salsa*; IM stands for *Medicago sativa L.*, and CK stands for the control group with no intercropping. Means with different lowercase letters in the same column represent significant differences at $P<0.05$

Discussion

Soil surface evaporation is an important factor affecting salt accumulation in saline-alkali soils in arid areas (Schofield and Kirkby, 2003) because the evaporation in this area exceeds precipitation. Therefore, the reduction in soil surface evaporation is necessary to reduce surface salt accumulation. In our experiments, the soil evaporation was significantly reduced by growing halophytes in bare strips between the rows of plastic film in the middle and late stages in the two-year experiment (*Table 1*). Planting halophytes reduced soil surface solar radiation and decreased wind speed, thereby reducing soil evaporation (Li et al., 2013). The canopy cover was highest for *Suaeda salsa* and more solar radiation was intercepted; thus, intercropping *Suaeda salsa* in the areas between the rows of plastic film resulted in the largest reduction in soil surface evaporation. The canopy cover of halophytes was lower in 2015 than in 2014 and there was no significant difference in the evaporation rate between the IM and CK treatments in 2015. A possible reason is that the amount of irrigation in the early growth period was larger in 2014 than in 2015 (*Figure 3*) and the halophytes exhibited better growth in 2014 than in 2015. The IM treatment resulted in greater ET because the canopy cover of *Medicago sativa* L. was lower than that of the other intercropping treatments.

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Intercropping halophytes reduced the accumulation rate of soil salt and soil sodium ions. It decreased the soil salt accumulation rate by 50%-134% and 74%-125% in the 0-40 cm and 0-100 cm deep soil layers in both years compared to the CK. The accumulation rate of the soil sodium ions decreased by 29%-138% and 17%-148% in the 0-40 cm and 0-100 cm deep soil layers compared to the CK. There are two reasons for this: first, the canopy cover of the halophytes reduced the soil surface evaporation, which reduced the accumulation of soil salt and soil sodium ions. Second, the halophytes absorbed the soil salt and sodium ions (Zhou et al., 2019). The IS treatment resulted in a reduction in the accumulation rate of soil sodium ions, and this treatment was more effective than the other treatments. *Suaeda salsa* has a higher canopy cover than the other halophytes in arid-saline environments. Intercropping *Cuminum cyminum* L. also resulted in a reduction in the accumulation rate of the soil salt and sodium ions compared to the CK. In addition, *Cuminum cyminum* L. can be harvested because it is a good condiment with high economic value. Intercropping *Medicago sativa* L. also reduced the soil salt compared to the CK, and there was no significant difference in the desalination effect compared to the other halophytes. *Medicago sativa* L. is a forage crop with high nutritional value (Zhao et al., 2019). It is known as the king of pasture and can survive in light saline-alkali soil. Studies have shown that *Medicago sativa* L. has good salt and drought tolerance and it is a legume which could increase soil fertility and improves the soil. The halophytes (*Suaeda salsa*, *Medicago sativa* L., and *Cuminum cyminum* L.) are economic and forage crops and provide good yield; therefore, their overall benefit is higher than that of CK.

Conclusions

Intercropping halophytes (*Suaeda salsa*, *Medicago sativa* L., and *Cuminum cyminum* L.) in cotton field reduced the accumulation rate of soil salt and soil sodium ions, as well as the soil surface evaporation in the cotton field. The accumulation rate of soil sodium ions was highest for intercropping *Suaeda salsa*. Intercropping halophytes had little effect on the cotton yield and biomass. The results of this study provide guidance for the improvement of light and medium saline-alkali soils. Future studies should investigate the suitability of different halophytes in cotton fields for the removel of soil salt from different types of saline soil.

Acknowledgments. This project was supported by the National Natural Science Foundation of China (No. 51379173) and the Shaanxi Provincial Natural Science Basic Research Program (No. 2018JM5051).

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