Effects of timing and duration under brackish water mulch drip irrigation on cotton yield in northern Xinjiang, China

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Abstract: The brackish water is an important potential water source and has frequently been utilized to drip-irrigate cotton due to the water shortage in the arid region of Xinjiang, northwestern of China. The brackish water is usually saline water with salinity ranging from 1 g/L to 5 g/L, which is widely distributed in this area, so the reasonable use of that brackish water may not only play a vital role in the local agricultural production, but also save plenty of freshwater. However, irrigation with brackish water usually causes the reduction of crop yield and soil salinization which can negatively impact plants through three major components: osmotic, nutritious and toxic stresses. Therefore, a field experiment, with eight different time-series irrigation modes using brackish water (3.5±0.2) g/L and freshwater (<1 g/L), beneath a combined film and drip-irrigation system was carried out to study the changes of soil salt content and cotton yield aiming to search for a balanced method during the 2 cotton growing seasons in 2012 and 2013. The results indicated that the time-series irrigation modes determined the soil salinity and moisture distribution based on observed spatio-temporal distribution of water content and electric conductivity, and soil salinity generally gathered at the depth of 0-10 cm and 60 cm of soil with the increase of irrigation quota. Moreover, the results demonstrated that the yields of cotton which was grown using brackish water and freshwater were better than those only using freshwater and the soil salinity with reasonable irrigation timing was not accumulated obviously.

Keywords: brackish water, mulch drip irrigation, timing and duration for irrigation, irrigation scheduling, cotton
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1 Introduction

The declining availability of fresh water has become a worldwide problem, which limits sustainable development of the agriculture[1], especially Xinjiang belongs to arid region which is located in northwestern of China. Over 70% of river water in Xinjiang has been developed for the agricultural production irrigation, and more than 70% of the developed rivers are inland which may dry up at the lower reaches intensifying desertification[2]. Mulched drip irrigation which is a method that combines drip-irrigation and plastic film applied at the land surface has been widely used for saving water and increasing water-use efficiency by reducing evaporation and deep percolation since the early 1990s, and was applied to over 15.3 million hm^2 in Xinjiang in 2009[3, 4]. However, mulched drip irrigation cannot deal with the water-shortage problem completely. Irrigation with brackish water provides a possibility to

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meet increased water demands[5]. Farmers have used brackish water from shallow underground sources to overcome drought and increase crop yields[6,7].

Shallow brackish water that has reserved about 1.3×10^{11} m^3 with total dissolved solids (TDS) of 2-3 g/L is distributed widely throughout north and north-west China, where freshwater is in shortage[8]. Drip irrigation for cotton, a highly salinity tolerant plant, with brackish water is increasing in Xinjiang[9]. Mulched drip irrigation with brackish water has been a new field practice[10]. However, one of the most serious problem of using brackish water is that increases the risk of soil salinization, which negatively impact plants[6,7,11]. A number of studies have taken to research the influence on plants of irrigation with brackish water under film. Magaritz and Nadler[12] found that the brackish water strongly diminished the growth and size of plants as compared to fresh water plants. Brackish water is used to provide moisture for plants and wash salt, and different effects of crop growth and yields will be brought because of the different content of salt in brackish water, irrigation methods and systems, etc.[8,13-15] Based on field experiments of mulched drip irrigation using brackish water on cotton, Wang et al.[10] found that the soil salinity increased during the growing season but flood irrigation after harvesting leached the accumulated salts and returned the salinity to background levels.

Brackish irrigation water strongly diminished the crop yield in cotton[15], as compared to freshwater irrigation. However, information regarding the mechanisms involved in the process and its technical feasibility is scarce. The objective of the present work is to study the yields difference of cotton which was grown using brackish water and freshwater were better than those only using freshwater, and to determine the optimal timing and duration under brackish water mulch drip irrigation in which the increase crop yield is technically feasible.

2. Materials and methods

2.1 Location and soil

The experimental site is in the Key Laboratory of Modern Water-saving Irrigation of Shihezi University (E85°59'47", N44°19'28"), which is located in an oasis in alluvial plain of the Manas river, the Junggar basin, north of Tianshan mountain, in the arid northern part of Xinjiang. The land surface elevation is about 300-400 m above the mean sea level. The groundwater level is deep which its annual change is about 7-11 m, and the effect of groundwater salinity on soil layer of 0-180 cm is very small.

Soil texture, which was transformed from desert sierozem into cultivable grey desert soil because of curing reaction, was loam in the experimental field. Besides, the parent material layers made by loess were below 50 cm depth. Some selected soil physical and chemical properties are listed in Table 1.

Table 1 Soil textures and properties in the plot-test field in Shihezi, Xinjiang Region

Depth /cm	Soil texture	Bulk density /g cm^{-3}	Saturated moisture /cm^3 cm^{-3}	Water holding capacity /cm^3 cm^{-3}	Soil salinity /g 100g^{-1}
0-5	sandy loam	1.46	0.37	0.28	0.28
5-10	medium loam	1.59	0.44	0.43	0.21
10-20	medium loam	1.69	0.43	0.32	0.19
20-40	medium loam	1.71	0.42	0.31	0.17
40-60	heavy loam	1.76	0.38	0.27	0.19
60-80	heavy loam	1.77	0.37	0.27	0.19
80-100	heavy loam	1.74	0.37	0.27	0.23

2.2 Climate and weather conditions

This region has a continental arid temperate climate, with a hot, dry summer and cold winter. The mean annual precipitation of approximately 213 mm; the potential evapotranspiration was 1342 mm; the sunshine time was 2705 h; and the mean annual temperature, the highest and the lowest temperatures were 7.7℃, 37.8℃ and –15.5℃, respectively. The average temperature and rainfall were given in Figure 1. The annual changing of groundwater table was between 7 m and 11 m.

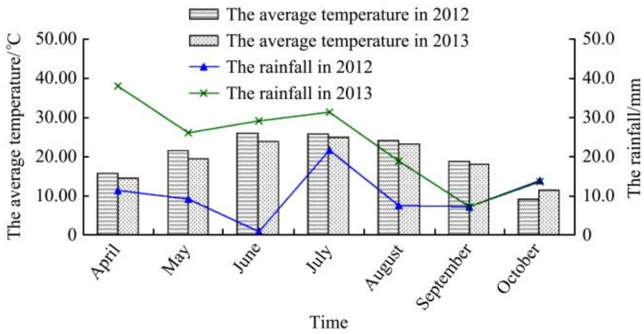


Figure 1 Average temperature and rainfall in 2012 and 2013

2.3 Treatments and experimental design

The experiment was conducted during two cotton growing seasons (from April to October) in 2012 and 2013, and the experimental plot was 5.5 m ×10 m cotton field. Beside the experimental plot, there was a weather station and an approximate 150 m depth aquifer well, which was drilled to measure the groundwater quality and irrigate through fresh well water (salinity ≤ 1 g/L). The weather station had been in use at the site for several years, and was used to observe the microclimatic factors such as light intensity, air temperature and humidity, wind speed and direction, dew point, barometric pressure, precipitation and solar radiation.

Irrigation water was prepared according to local saline groundwater[15,17] and experimental man-made preparation water. The ratio of the mixing solution quality was $NaHCO_3$ (0.24): Na_2SO_4 (0.99): NaCl (1.71): $MgCl_2$ (0.23): $CaCl_2$ (0.32). The electrical conductivity (EC) of the brackish water used for irrigation was 2.8-3.1 ms/cm, and the salinity solution concentrations were approximate (3.5±0.2) g/L. The salinity of fresh well water is (1.0±0.2) g/L. During the growth period duration of cotton, the artificial brackish water and fresh water with alternate scheduling drip-irrigated the topsoil under plastic film. In this study, the four individual periods (the seeding period: June 2nd, the flower bud period: June 30th, the blooming period: July 21st and the opening period: Aug. 11th) were designed for soil sampling. The actual soil sampling time is before irrigation and after irrigation in each period. The actual schedules and amounts of irrigation water are given in Table 2. Each irrigation experiment was four replicas.

Table 2 Test design in the plot-test field

Treatments	Seeding stage	Budding stage	Boll stage	Opening stage
1	d	d	d	d
2	d	d	x	d
3	d	x	d	d
4	d	d	x	x
5	d	x	d	x
6	d	x	x	d
7	d	x	x	x
8	x	x	x	x

Note: "d" means fresh water, "x" means brackish water.

The tillage started at May 1st with the dry seeding and wet budding method. During the growth period duration of cotton, the calculated fertilizer was irrigated using drip irrigation method. The fertilizer amount of each irrigation was following: the phosphatic fertilizer was 150 kg/hm^2 and the urea was 300 kg/hm^2. The total quantity of irrigation water applied during the entire growing season was 442 mm. Each irrigation event lasted a few hours and the discharge rate was about 3 L/h for a dripper. A 7 d irrigation-event frequency was applied after starting the drip irrigation and the total number of irrigation time was 11. Some parameters of irrigation were listed in Table 3. The theoretical cotton yield was calculated through the statistic results of cotton bolls in the experimental plot.

Table 3 Irrigation application during the cotton growth seasons

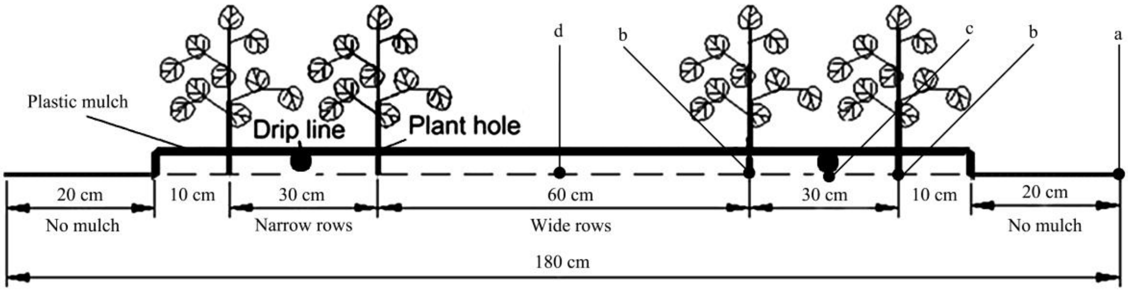
Month	Irrigation date	Interval days/d	Cumulative time/d	Dripping amount/mm	Total dripping amount/mm	Irrigation times
June	June 2nd	-	50	37	37	1
	June 9th	7	57	30	67	2
	June 16th	7	64	30	97	3
	June 23th	7	71	45	142	4
	June 30th	7	78	52	195	5
July	July 7th	7	85	52	247	6
	July 14th	7	92	52	300	7
	July 21st	7	99	45	345	8
	July 28th	7	106	37	382	9
August	Aug. 4th	7	113	30	412	10
	Aug.11th	7	120	30	442	11

2.4 Plant material and cultivation practice

Cotton is one of the major economic crops in Xinjiang. The experimental cotton is Xinluzao No.7[18] which is typical and representative. It was cultivated by Shihezi Cotton Institute. In addition, it takes 135 d to mature, and 3250 degrees effective accumulated temperature was necessary.

There were 3 mulches in each plastic mulch experimental field, whereby each plastic mulch width was 140 cm, and the no-mulch strips between pairs of mulches were 20 cm wide. The wide-rows zone, narrow-rows zone and no-mulch zone are defined (Figure 2) according to the location of the cotton plants.

Drip lines of the experimental field were set at the mode of 'one mulch, two drip lines and four rows' (Figure 2), which indicated that two drip lines, beneath the mulch, were each in the middle of a narrow-rows zone. The spacing between drippers along the line was 30 cm. It was more suitable for a loamy field than another drip-line arrangement of 'one mulch, one drip line and four rows' which indicated that one drip line, beneath the mulch, was in the middle of the wide-rows zone after the experiences of the farmers. The 'one mulch, two drip lines and four rows' mode was the only style in the experimental field could conveniently provide irrigation water for roots and reduce deep percolation.



Note: a. In-mulch; b. Under-dripper; c. Cotton row; d. Inter-mulch

Figure 2 Schematic diagram flow domain delineation for plot of crop planting and dripper location

2.5 Measurements

Before treatments, the soil samples in each experimental point were collected and soil-water content and EC were measured using densitometers (DDP-210, Soil Research Institute of Chinese Academy of Sciences, Nanjing, China) at different depths down to 60 cm, in the wide rows, narrow rows and bare soil strip (no mulch). These data were measured in each growing season, thus, four times measurement was needed in whole experiment.

The soil moisture and soil salt samplers were actually placed at different vertical planes (a, b, c, d shown in Figure 2) along the drip line to ensure enough space for each measurement. The soil water content was determined following the soil salinity measurement was determined following and the soil electrical conductivity was determined following Corwin and Lesch[19]. Water holding capacity (WHC) and bulk density (BD) were measured by the methods of Black.

Three similar plants were chosen to measure height by tape measure, and these plants were divided into roots, leaves, stems, bolls and buds, and the dry weight of each was determined in each growing season. Leaf area, which employed the average of measurement of all leaves, determined every 14 days. Theoretical yield was calculated by the weight of cotton batting in a part of experimental region (about 2 m^2).

The results obtained for each of the dependent variables in this study were analyzed statistically using a model that included treatment and replication as independent variables. All the statistical tests were performed using SPSS software (SPSS Inc., version 19.0). The soil water and salt distribution was represented using Surfer software (version 9.0).

3 Results and discussion

3.1 Change characteristics of average water content

The change characters of average water content in the 0-60 cm depth soil under brackish water mulch drip in the two irrigation periods (2012-2013) were showed in Figure 3. The change characters of soil water content between before irrigation and after irrigation obviously showed that the trough of wave was appeared before irrigation and the wave crest was appeared after irrigation, the variation range was from 11.47% to 20.02%, and the change tendency in two irrigation period was consistent. Following the high to low of the soil average water content, the order of each treatment was No.1>No.2 >No.3>No.4>No.5>No.6>No.7>No.8. The soil water content showed a decrease tendency with the number of brackish water irrigation time increasing. The highest soil water content scheme was No.1 and the value was 16.168%. The lowest soil water content scheme was No.8 and the value was 14.212%.

The reason of different water contents between the eight irrigation modes may be that the slight saline water irrigation can change the soil structure characteristics to some extent, which in the process of brackish water infiltration, the salt ions are exchanged with the original ions in the soil is to increase the content of sodium ion will make the soil particles hydration degree increases, and the change of soil aggregate structure, soil particles. With the increase of hydration degree, the particles are easier to disperse. Small particles in the water driven down and accumulated gradually, finally blocked. The water channel forms a dense weak permeable layer, which hinders the deep water leakage and intensifies the difference of soil water content in the upper and lower layers[20,21]. With the increase of brackish water irrigation flux, the effect of changing soil structure characteristic of brackish water was more and more serious, which increased the ratio of fine tube, reduced water conductivity and the soil water potential. Besides, the water infiltration was inhibited, most of the water stagnated in the upper soil, which thus increased the evaporation of surface soil, resulting in the overall decline in soil moisture content of 0-60 cm.

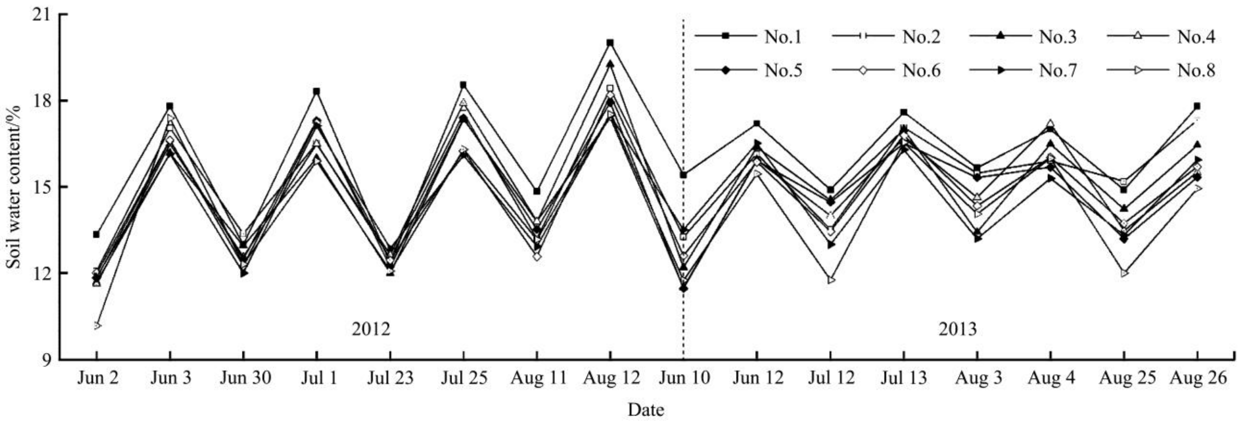


Figure 3 Changes of soil water content in the 0-60 cm depth soil under brackish water mulch drip in the two irrigation periods

3.2 Change characteristics of average salinity

In order to judge the security of irrigation with salinity water, datum of different treatments were measured by the densitometers. The change soil salt content in the 0-60 cm depth soil under brackish water mulch drip in the two irrigation periods (2012-2013) were showed in Figure 4. There was obvious difference between initial and final soil salt content in 2012 except treatment 1 which was irrigation by fresh water (Figure 4). Besides, it can be easily concluded that with the increasing number of brackish water irrigation time, the soil salinity change ratio showed a same tendency. The maximum of soil salt content at the end of 2012 was about 0.40 g/100 g (treatment 8). So, the curve of change ratio was convex.

The difference of soil salt content in 2013 were not very huge as 2012 because of the abundant moisture in 2013 (Figure 4). Abundant moisture could provide adequate fresh water to flush the accumulated salt out of the soil profile as flood irrigation. The maximum of soil salt content at the end of 2013 was about 0.25 g/100 g (treatment 8). So, the curve of change ratio was hollow.

According to the experiment from 2012 to 2013, we can understand that the soil salt content in treatments 6 and 7 were keep stable at 0.20 g/100 g and 0.23 g/100 g, respectively (Figure 4). Besides, treatments 1 to 5 were decreased in different degrees, and the notable data (treatment 1) fell by 0.7 g/100 g. The treatment 8 was isolated from other treatments because of the increasing trend, and it was raised to 0.24 g/100 g from 0.22 g/100 g.

In addition, the curve of change ratio was similar to linear function. Following the high to low of the soil average salt content, the order of each treatment was No.8>No.7>No.6>No.5>No.4>No.3>No.2>No.1, in other words order of the soil salinity accumulation from high to low from the eight schemes was: xxxx > dxxx > dxxd > dxdx > ddxx > dxdd > ddxd > dddd. The scheme No.1 (dddd) was beneficial for soil salinity removing, and the ratio for soil salinity removing was 0.28% (2012) and 6.13% (2013), meanwhile, the scheme No.8 (xxxx) was difficult for soil salinity removing, and the soil salinity accumulation ratio was 82.96% (2012) and 56.23% (2013). Comparison of the soil salinity accumulation ratio in 2012 and 2013, the soil salinity accumulation phenomenon only was observed in the scheme No.7 (–0.25%) and No.8 (–12.23%). The results showed the drip irrigation under plastic film through the brackish water and fresh water with alternate schedule was beneficial for the soil salinity removing.

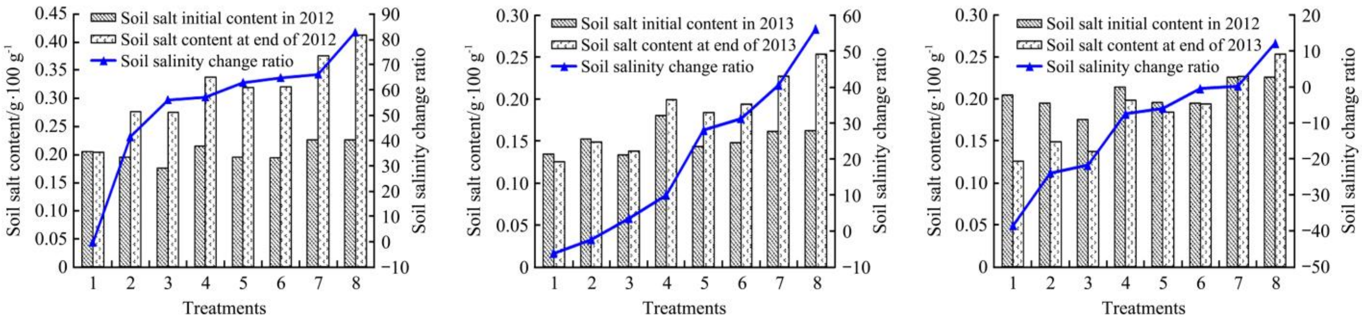


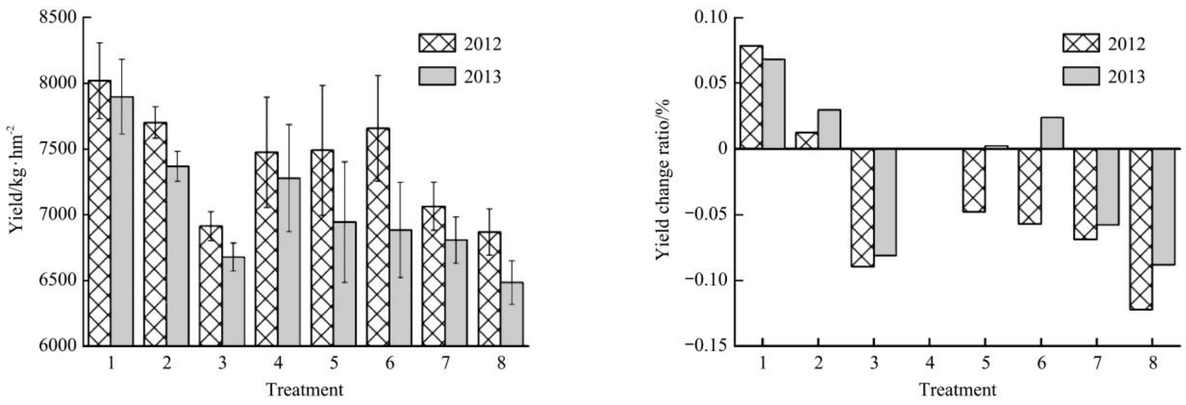
Figure 4 Changes of soil salt content in the 0-60 cm depth soil under brackish water mulch drip in the two irrigation periods

3.3 Effects of change characteristics on cotton yield

The change characters of cotton yield (2012-2013) and the comprehensive analysis between cotton yields and salt content with timing of brackish water irrigation were showed in Table 4 and Figure 5. The cotton yield of the scheme No.1 was assumed to be a reference yield in this study. There were three schemes showed the reduction of cotton output: No.8 (8.11%), No.3 (7.51%) and No.2 (5.48%), meanwhile, there were four schemes showed the increase yield and the highest ratio of increase yield was No.4 (7.30%).

Table 4 Comprehensive analysis between cotton yields and salt content with timing of brackish water irrigation

Treatments	The total number with brackish water	Total dripping amount for brackish water/mm	Cotton yield /kg hm^{-2}	Soil salinity the rate of increase/%	Water saving rate/%	Production rate unit /%	the yield of the amount of salt added unit /kg hm^{-2} (g (100g)$^{-1}$)$^{-1}$
1	0	0	7374.90	16.52	0	-	440.46
2	5	239.88	6935.28	17.20	54	–1.96	395.84
3	3	104.95	6824.77	15.68	24	–5.71	425.83
4	7	299.85	7964.89	20.69	68	2.07	381.61
5	5	164.92	7215.73	18.98	37	–2.02	365.80
6	8	344.83	7534.07	19.43	78	0.26	379.27
7	10	404.8	7268.78	22.64	92	–0.97	303.99
8	11	442.28	6298.60	23.94	100	–1.79	270.82



a b

Figure 5 Analysis of yield between 2012 and 2013

The change characters of cotton yield between irrigation with brackish water and irrigation without brackish water obviously showed that the use of brackish water especially on flower age stage and boll opening stage increased the cotton yield which is similar with the previous researches[22-26]. However, with the increase of flux and time of brackish water, the yield may reduce to a certain degree which the ion broke the osmotic pressure of cotton[25]. Besides, the change tendency in two irrigation periods was not consistent which was showed in Figure 5. It's different with the results of [25], which is consistent during the experiment. The reason may be due to the large rainfall in 2013, which is beneficial to the growth of cotton. On the one hand, it also leads to a small increase in temperature during the whole growth period. The smaller temperature difference is not conducive to the accumulation of dry matter and the formation of economic yield, and is not easy to obtain high yield. Therefore, there will be a smaller reduction in 2013.

4 Conclusions

Through two years study, the increasing yield rates of the different treatments (from No.2 to No.8) were: –5.48%, –7.51%, 7.30%, 0.19%, 3.04%, –2.36% and –8.11%, respectively, which shows that we demonstrated that the reasonable timing and duration of the brackish water and fresh water irrigation in the growing period of cotton were benefited from keeping a positive effect on yield compare as the fresh water irrigation. On the other hand, the fresh water saving rate is 68% (No.4) and 78% (No.6), so the reasonable timing and duration of the brackish water and fresh water irrigation were beneficial for saving fresh water.

Acknowledgments

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