water

MDPI

Article

Effect of Periodic Winter Irrigation on Salt Distribution Characteristics and Cotton Yield in Drip Irrigation under Plastic Film in Xinjiang

Jinping Feng [1,2], Hongguang Liu [1,2,*], Gang Wang [3,*], Rumeng Tian [1,2], Minghai Cao [1,2], Zhentao Bai [1,2] and Tianming He [1,2]

[1] College of Water & Architectural Engineering, Shihezi University, Shihezi 832000, China; feng2468787347@163.com (J.F.); trm563471400@163.com (R.T.); caominghai147@163.com (M.C.); baizt2020@163.com (Z.B.); aming202003@163.com (T.H.)
[2] Key Laboratory of Modern Water-Saving Irrigation of the Xinjiang Production and Construction Corps, Shihezi 832000, China
[3] Xinjiang Academy of Agricultural and Reclamation Science, Shihezi 832000, China
* Correspondence: liuhongguang-521@163.com (H.L.); wg5791@163.com (G.W.); Tel.: +86-0993-2057229 (H.L.); +86-0993-2696098 (G.W.)

Citation: Feng, J.; Liu, H.; Wang, G.; Tian, R.; Cao, M.; Bai, Z.; He, T. Effect of Periodic Winter Irrigation on Salt Distribution Characteristics and Cotton Yield in Drip Irrigation under Plastic Film in Xinjiang. *Water* **2021**, *13*, 2545. https://doi.org/10.3390/w13182545

Academic Editor: Antonio Lo Porto

Received: 23 August 2021
Accepted: 11 September 2021
Published: 16 September 2021

Abstract: Winter irrigation is an effective means of salt leaching, but the long-term effect on salinity is unclear. In 2008–2019, three different soil types of farmlands were selected as the study area by drip irrigation under film mulch combined with periodic winter irrigation in the non-growth period. The salinity of 0–150 cm as well as the survival rate and yield of cotton in the non-growth and growth periods were monitored, respectively. The mass fraction of soil salt decreased rapidly under winter irrigation, and then, the salt content in each observation layer increased with years of cultivation. After 10 years of application, the soil salt content basically stabilized at a low level. In 2008, the salinity of the 0–150 cm observation layer of loamy clay, loam, and sandy loam varied within 6–60, 10–65, and 4–22 $g \cdot kg^{-1}$; after four winter irrigations in 2019, corresponding values dropped below 5.74, 3, and 4.76 $g \cdot kg^{-1}$, respectively. The salinity returns rate of the different observation layers all exceeded 40%. The desalination rate of the different soils after four winter irrigations all exceeded 63.52%. Cotton survival rate and yield in different soils were directly proportional to each other. After the second winter irrigation, the survival rates on the different soils all exceeded 60%. The results of this study can provide technical support for the sustainable development of different types of soil, farmers' income increase, and salinization land improvement.

Keywords: periodic winter irrigation; drip-irrigation under film mulch; different soil qualities; soil salinity; cotton yield; Xinjiang

1. Introduction

As arid area accounts for about 40% of the world's land area, drought and salinity are important factors restricting the development of sustainable agriculture in arid areas [1]. It is particularly important to select appropriate economic crops in arid areas [2]. Cotton is one of the most important crops in the world and an important salt-tolerant and economic crop in arid areas [3]. However, water shortage and soil salinization severely restrict the sustainable development of the cotton industry [4,5].

In response to the problem of water shortage, Xinjiang has vigorously developed cotton drip-irrigation technology under film mulch [6]. This technology has the advantages of saving water and fertilizer [7], maintaining moisture and increasing temperature [8], and effectively increasing the growth of crop roots [9], thereby increasing cotton yield [10]. The area used for drip irrigation under film mulch has increased from 1.67 hm^2 in 1996 to the current 300×10^4 hm^2 [11]; and crops grown have extended to corn [12], sugar beet [13], wheat [14], potato [15], and maize [16] as food and cash crops. Some scholars have explored the sustainability of drip irrigation under film mulch [17,18]. Drip irrigation under film mulch is local irrigation and does not produce deep leakage, making the traditional irrigation and drainage system difficult to maintain. Drip irrigation changes the vertical and horizontal distribution of salinity [19]. The salt in soil is not discharged [20], and the dynamic effects of irrigation and strong evaporation during the growth period can lead to secondary salinization of soil, aggravating the degree of soil salinization in farmland [21]. Farmland salinization is a worldwide problem, and the salinization of soil in Xinjiang has always restricted the efficient development of oasis agriculture, and the management and improvement of saline-alkali land has been a focus of attention by experts and scholars at home and abroad [22].

Drip irrigation under film mulch uses intermittent irrigation in the salt accumulation area of the cotton root zone, which can effectively reduce the amount of water required for salt leaching [23]. The principle is to fully leach the salt in the soil pores through multiple cycles, thereby improving leaching efficiency [24,25]. However, intermittent irrigation with many irrigation cycles and in inadequate, small amounts only affects the shallow soil and cannot leach salt to deep layers [26]. In an arid climate, due to strong evaporation [27] and the irrigation water itself containing salinity, this irrigation method will increase the degree of salinity on the soil surface [28]. Under conditions of drip irrigation under mulch in arid areas, flood irrigation during non-growth periods is an effective method to inhibit soil salinization [29], which can control and reduce soil salt in the root zone [29], and at the same time has a better effect on soil salt leaching [30,31]. Showed that [32,33] the high-rate drip irrigation with 300 mm in winter irrigation in the northern Xinjiang region is beneficial to water retention, soil moisture, and salt. Zhao [32] found that winter irrigation of 300 mm under drip irrigation conditions was most appropriate under experimental conditions and only leached salt to 300 cm below the cultivated layer but also produced a higher yield of 6107.75 kg·hm^{-2}. In simulations using the SaltModel model in southern Xinjiang, Shan [33] concluded that 300 mm was a reasonable amount of winter irrigation after verifying the rationality of the model. He [34] found in the southern Xinjiang that winter irrigation during the non-growth period of 300 mm and for the growth period of 334 mm effectively increased the yield and water use efficiency of cotton to 7146.4 kg·hm^{-2} and 1.40 kg·hm^{-2}, respectively.

The freezing and thawing process during the non-growth period is significant, as it exacerbates the problem of soil salinization [35]. In local agricultural production practice, flood irrigation during non-growth periods is widely used to solve the problem of salinization in cotton fields under mulch drip irrigation [36]. There have been studies on the effect of winter irrigation water on salt leaching [28] and water and salt movement [32,37], but there have been relatively few studies on the long-term effects of winter irrigation on salinity in different soils. Based on the continuous monitoring and analysis of 12-year drip irrigation in cotton fields, we explored the long-term effects of periodic winter irrigation on cotton field salinity, rate of salt accumulation, cotton survival rate, and yield changes and quantitatively evaluated salt-leaching efficiency during winter irrigation in the study area. The results of this study provide a scientific basis for regional salt control, improvement, and sustainable farmland development.

2. Materials and Methods

2.1. Overview of the Test Area

In 2021, the growth rate of global cotton demand will increase, and China's cotton imports will be huge [3]. Xinjiang is China's largest cotton production base. In 2019, Xinjiang's cotton planting area and total output were 2540.5 × 10^3 hm^2 and 500.2 × 10^7 kg, accounting for 76.08% and 84.94% of the country's total, respectively; the unit yield was 1969.1 kg/hm^2, representing 111.65% of the national cotton output value per unit area yield. [38]. The selection involved 147 regiment 15 companies (86°0′52.37″ E, 44°40′41.40″ N, altitude; 358.75 m) and 147 regiment 17 companies (86°3′40.871″ E) in Manas County, Xinjiang, from 2008 to 2019 (44°38′13.39″ N, altitude; 364.12 m), 147 group 22 companies (86°1′27.38″ E, 44°43′1.64″ N, altitude; 357.96 m), and three different soil farm fields for field experiments (Figure 1). According to the meteorological information provided by the Mosuowan Weather Station, the inter-annual average temperature of the test area during 2008–2019 was 8.4 °C, inter-annual sunshine duration was 2399.3 h, inter-annual average evaporation was 1820.9 mm, inter-annual average rainfall was 108.89 mm, and inter-annual frost-free period was 173–205 days. The average temperature and minimum temperature in the study area showed a significant increasing trend, and frost-free period showed a significant increasing trend. Xinjiang has a temperate continental climate. The average daily temperature for more than 90 days is below 0 °C, and the lowest temperature can reach −35 °C. The groundwater level from 2008 to 2019 was found to be between 3.3 m and 14.23 m by monitoring groundwater observation wells. The groundwater level drops sharply in summer and autumn; spring and winter are the main recharge periods, and the groundwater level rises due to the lateral recharge of groundwater. The soil of the test area was sampled and analyzed in 2008. Based on the international classification standard of soil texture [39], the soil physical indicators of different soil quality farmland are shown in Table 1. The test area associated with Company 15 was marked as the No. 1 plot, and its soil was loamy clay; the test area associated with Company 17 was marked as the No. 2 plot, with loam soil; and the test area associated with Company 22 was marked as plot 3, and the soil was sandy loam.

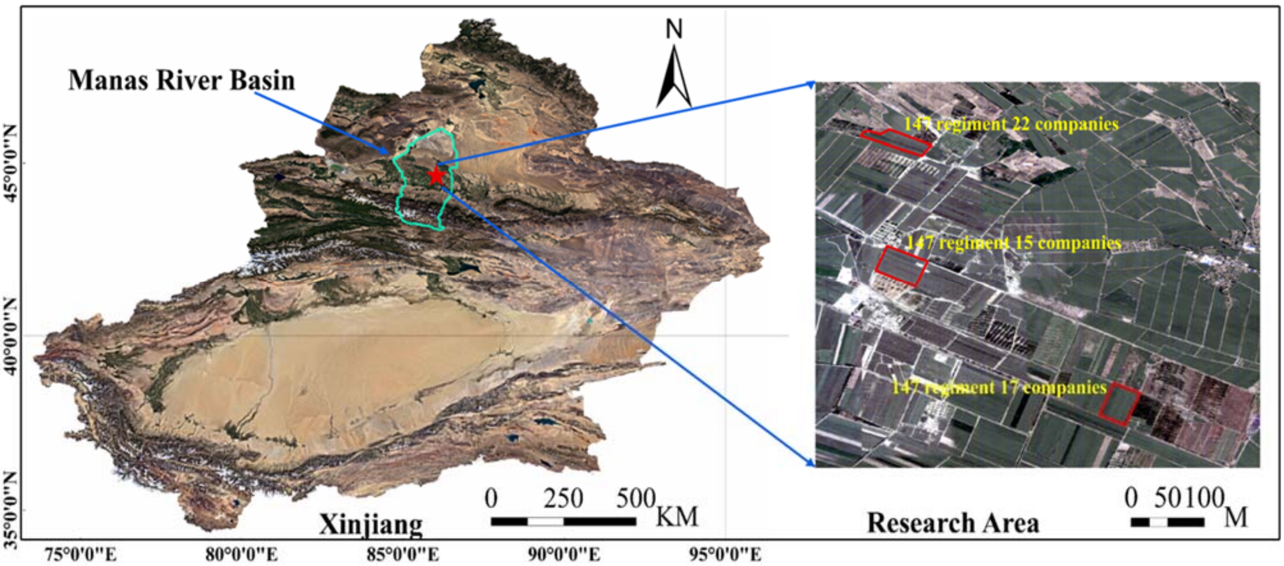


Figure 1. Location map of the study area.

Table 1. Physical indicators of different soil qualities in the study area.

	Soil Particle Composition/(%)			Organic Matter/(g/kg)	Porosity/(%)	Dry Bulk Density/(g/cm^3)
	<0.002 mm	**0.002–0.02 mm**	**0.02–2 mm**			
Loamy clay	42.33	36.15	21.52	21.32	39.2	1.43
Loam	13.42	44.4	42.18	19.9	43.3	1.54
Sandy loam	12.21	21.76	66.03	11.3	16.7	1.65

The irrigation water source in the study area was mixed irrigation of wells and canals: canal water comes from the Manas River, and salinity of the river water in the irrigation season was 0.502–0.673 g/L; the salinity of well water was 0.8–1.0 g·L^{-1}; salinity of the irrigation water source was ≤1 g·L^{-1}, and water quality of the irrigation water source met the requirements. Regiment 147 was a saline-alkali wasteland before reclaiming and planting cotton fields. In 2008, drip irrigation with film mulching was started (flood irrigation was not carried out in 2007), and by 2019, drip irrigation under film had been used for 12 years. The irrigation system in the study area is shown in Table 2. According to the growth and development of cotton and the influence of temperature, the ratio of fertilizer during irrigation differed, mainly urea and potassium dihydrogen phosphate, with annual application rates of 1142.35 and 729.33 kg·hm^{-2}, respectively. The fertilization method was drip-irrigation system of drip application with fertilizer supplied with water. The water source for winter irrigation was the Manas River for all the plots. According to local production and planting experience, on 6 November 2008, 3 November 2011, 7 November 2014, and in 2017 around 1 November, flood irrigation was carried out after deep loosening and plowing. The irrigation water volume was 2800 m^3·hm^{-2}. The water volume of four winter irrigations was inserted into the salt analysis chart in the form of double Y-axis through a histogram.

Table 2. Study area irrigation system.

Irrigation Date	Mid-April	Late April	Early May	Late May	Early June	Mid-June	Late June	Early July	Mid-July	Late July	Early August	Mid-August	Late August	Total
Irrigation quota/(mm)	18.23	27.55	27.55	27.55	34.43	34.43	41.32	48.20	55.09	48.20	41.32	41.32	41.32	486.50

The cotton variety was mainly Xinluzao 24 long-staple cotton, and the area of each of the three different soil cotton fields was 6.68 hm^2. The cotton planting pattern from 2008 to 2013 was one film, two tubes, and four rows (Figure 2), with row spacing of 20 cm + 40 cm + 20 cm and plant spacing of 10 cm. The planting pattern from 2014 to 2019 was one film, two tubes, and six rows (Figure 3); the spacing between wide and narrow rows of cotton was 66 and 11 cm, respectively; spacing between membranes was 60 cm; and plant spacing was 10 cm (i.e., 11 cm + 66 cm + 11 cm + 66 cm + 11 cm + 60 cm). The cotton fields in the study area adopted the common drip-irrigation deployment modes of "one film, two tubes, four rows" and "one film, two tubes, six rows," but research for many years mainly focused on the overall salt change in the root zone and drip irrigation. with little difference in irrigation water volume. The deployment mode has little effect on long-term salinity dynamics [40].

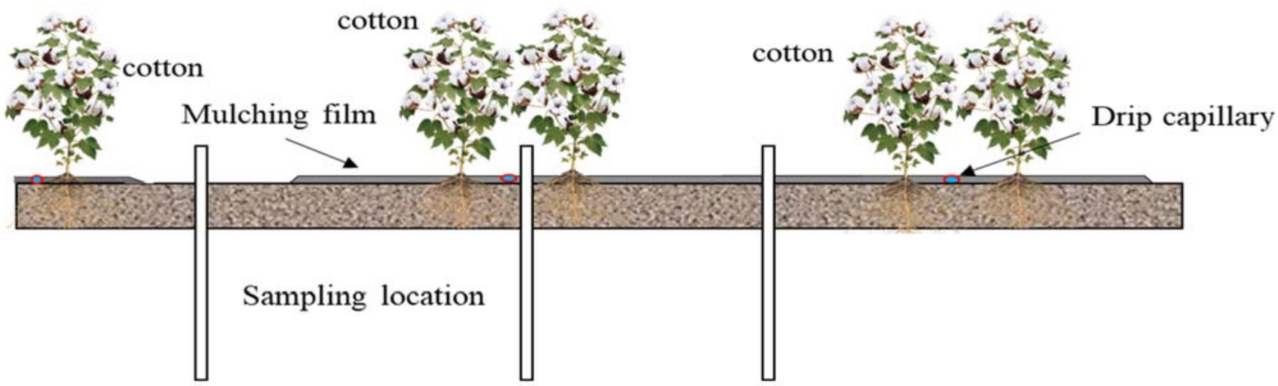


Figure 2. Planting mode with one membrane, two tubes, and four rows.

2.2. *Experimental Design and Analysis Methods*

Through continuous monitoring and analysis of non-growth and growth periods in different soil cotton fields, the long-term effects of periodic winter irrigation on salinity, salinity return, cotton survival rate, and yield of drip irrigation under mulch were explored. Sampling method: soil samples were collected by soil drills at a sampling depth of 1.5 m, and soil samples taken every 10 cm, put in an aluminum box, and taken back to the laboratory for water and salt determination. Sampling time: before spring sowing (after cultivating the ground and leveling) and after harvesting in different cotton fields, samples were taken twice during the non-growth period and once a month during the growth period; samples were taken between two irrigations. Sampling was divided into wide and narrow rows between films and bare ground between films. In order to resolve the uncertainty caused by the strong heterogeneity of soil salinity, sampling was repeated three times.

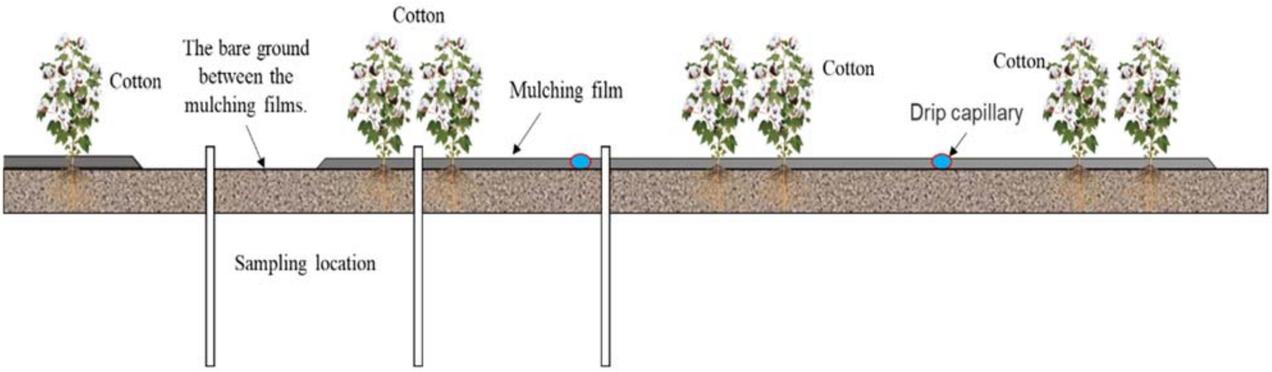


Figure 3. The planting mode of one film, two tubes, and six rows.

2.2.1. Soil Salt Content

The drying residue method was used to calibrate the soil salt content [19]: an aluminum box containing the soil sample was dried in an oven at 105 °C for 24 h; the dried soil sample was crushed and filtered with a 1-mm sieve. Soil samples (20 g) were mixed with 100 g of distilled water in a beaker with a soil-to-water ratio of 1:5, and the water-soil mixture was mixed with a glass rod; after standing for 2 h, it was filtered again, and a conductivity meter (Shanghai Lei Magnetic DDS-11A type) used to measure the soil electrical conductivity (EC) value. The calibration relationship between soil salt content and EC is shown in Equation (1):

$$SMF = 3.47 \times 10^{-2} \times EC + 0.89269 \ (R^2 = 0.997) \quad (1)$$

where SMF is the mass fraction of soil salinity (g·kg^{-1}), and EC is in µs·cm^{-1}.

Soil salinization level classification [39]: SMF ≤ 3 g·kg^{-1} indicated mildly saline soil, 3 g·kg^{-1} < SMF ≤ 6 g·kg^{-1} indicated moderately saline soil, 6 g·kg^{-1} < SMF ≤ 12 g·kg^{-1} indicated severely saline soil, and SMF > 12 g·kg^{-1} indicated saline soil.

2.2.2. Total Soil Salt

The salinity obtained is the data on the vertical point, and the point is converted into the observation layer by Formula (2); for example: 0–10 cm observation layer, 0–60 cm observation layer, and 60–150 cm observation layer. The calculation formula [41] for the total salt content of the soil observation layers at different depths (hereinafter referred to as total salt) is shown in Equation (2):

$$OSC = \int_0^x F(x)dx \quad (2)$$

where OSC is the total salt of the soil at a depth of 0–150 cm (g), $F(x)$ is a function of the salt content of each observation layer of the soil, and x is the soil depth of each calculate layer (m). The calculation formula of the salt content function of each observation layer of the soil is shown in Equation (3):

$$F(x) = \gamma\theta V \quad (3)$$

where γ is soil bulk density (kg·m^{-3}), θ is the soil salt content (SMF) of different depth layers (g·kg^{-1}), and V is the soil volume of different depth layers (m^3). When calculating the soil volume (m^3), the soil of each depth layer was regarded as 1 m in length and width, and the height is the depth value h (m) of the corresponding calculated observation layer. It can be calculated that $V = 1 \times 1 \times h$ (m^3).

2.2.3. Soil Desalination Rate

The soil-leaching efficiency (hereinafter referred to as desalination rate) is an important indicator for judging the desalination effect of farmland soil during winter irrigation. It is characterized by the salt mass fraction in the non-growing period, and its calculation [20] is shown in Equation (4):

$$DR = (M_1 - M_2)/M_1 \tag{4}$$

where DR is desalination rate (%), M_1 is the total salt of the observation layer at the end of the non-growth period of the winter irrigation year (g), and M_2 is the total salt of the soil observation layer at the beginning of the non-growth period of the next year after winter irrigation (g).

2.2.4. Degree of Soil Salinity

The salinity return rate (SRR) is one of the most direct evaluation methods for soil salinity return [5]: the SRR (%) from 2008 to 2019 is characterized by the total salt of each observation layer during the non-growth period and was calculated by the following (5):

$$SRR = (M_3 - M_4)/M_3 \tag{5}$$

where M_3 is the total salt of the observation layer at the end of the non-growth period of the calculation year (g), and M_4 is the total salt of the soil observation layer at the beginning of the non-growth period of the calculation year (g).

2.2.5. Survival Rate and Yield of Cotton

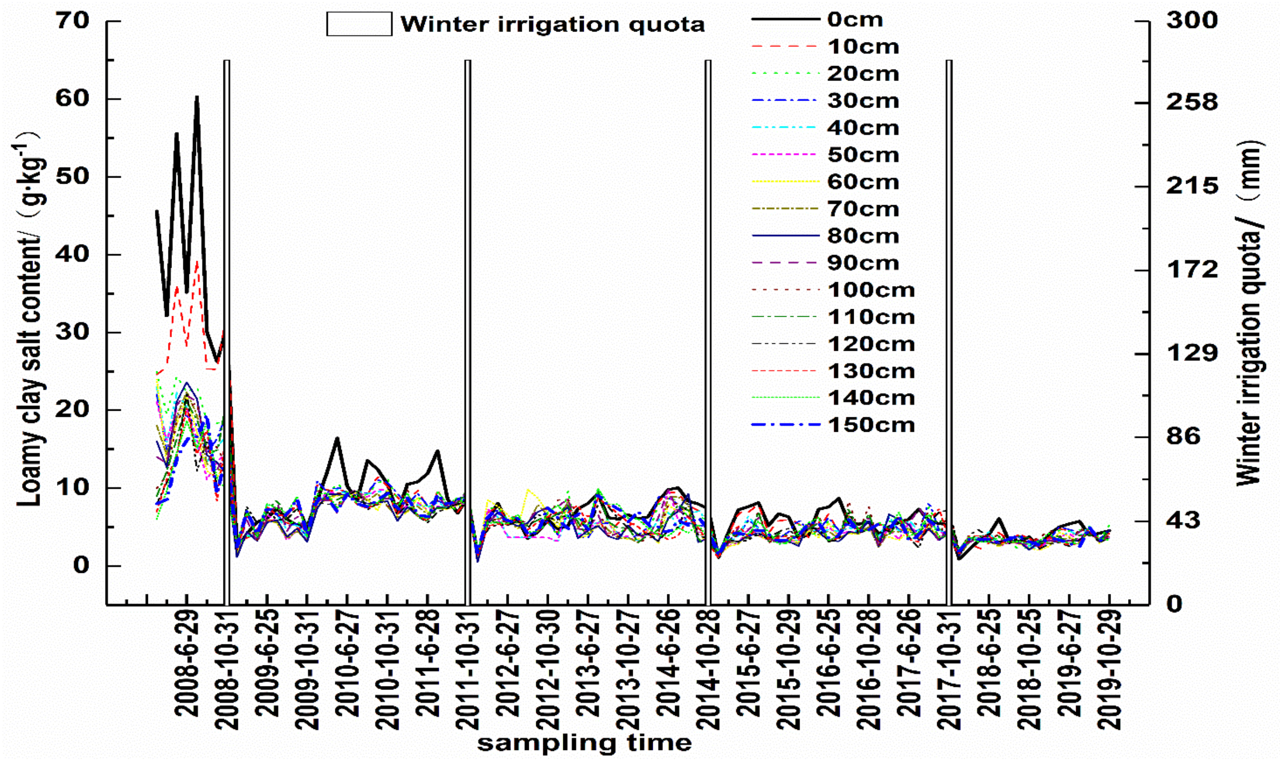
The survival rate of cotton is the number of remaining plants when cotton is mature divided by the theoretical number of plants [11]. Actual number of plants: when cotton matures, five discrete segments of 5-m-long whole film were randomly selected in each cotton field, and the number of cotton plants were counted. Theoretical numbers of plants: 1000 plants for one film, two tubes, and four rows and 1500 plants for one film, two tubes, and six rows. The final actual output of the farmers in the experimental area is the cotton field output [11].

3. Results

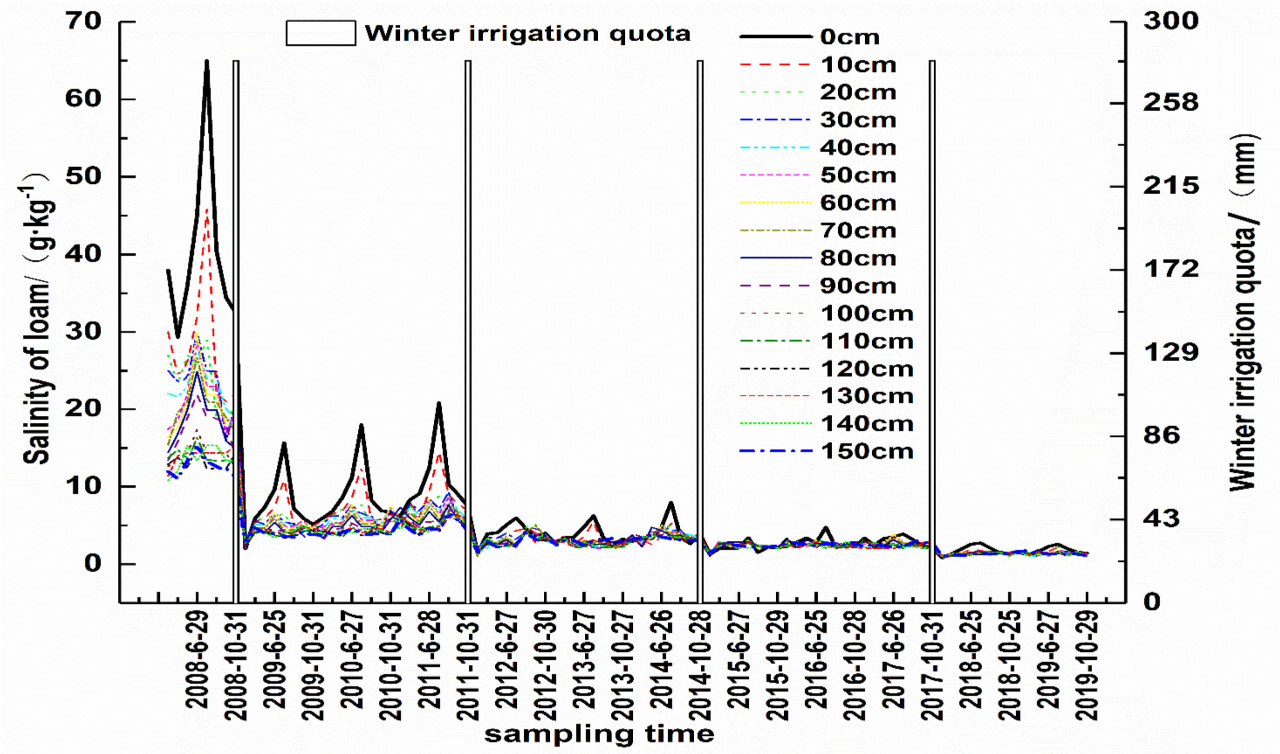
3.1. Long-Term Effects of Periodic Winter Irrigation on Different Soil Salinities under Mulch Drip Irrigation

From 2008 to 2019, based on the continuous sampling analysis of the growth and non-growth periods of each observation layer under long-term drip irrigation with different soil types, the average value of repeated sampling three times was used as the salt mass fraction of each observation layer. The average salt contents of each observation layer of the different soil types are shown in Figure 4.

This is a novel finding in this paper: before winter irrigation, the salt content of each observation layer was high and varied greatly. After four winter irrigations, the salt content of each layer gradually stabilized at a lower level. The salt content of the loamy clay layer of 0–10 cm during the growth period before winter irrigation fluctuated greatly and ranged within 25–60 g·kg^{-1}; the salt content of the layer of 20–150 cm was within 0–25 g·kg^{-1}. After four winter irrigations, the salt mass fraction was <5.74 g·kg^{-1}. The salinity content of loam in the growth period before winter irrigation fluctuated greatly, ranging within 24–65 g/kg; for 20–150 cm, salinity ranged within 11–28 g·kg^{-1}, and after four winter irrigations, it was <3 g·kg^{-1}. The 0–60 cm salt content of sandy loam during the growth period before winter irrigation fluctuated greatly, ranging within 9–21.6 g·kg^{-1}, and the 70–150 cm salt content was 3.6–10.8 g·kg^{-1} before the four different irrigation events; the salt mass fraction after winter irrigation was <4.76 g·kg^{-1}.

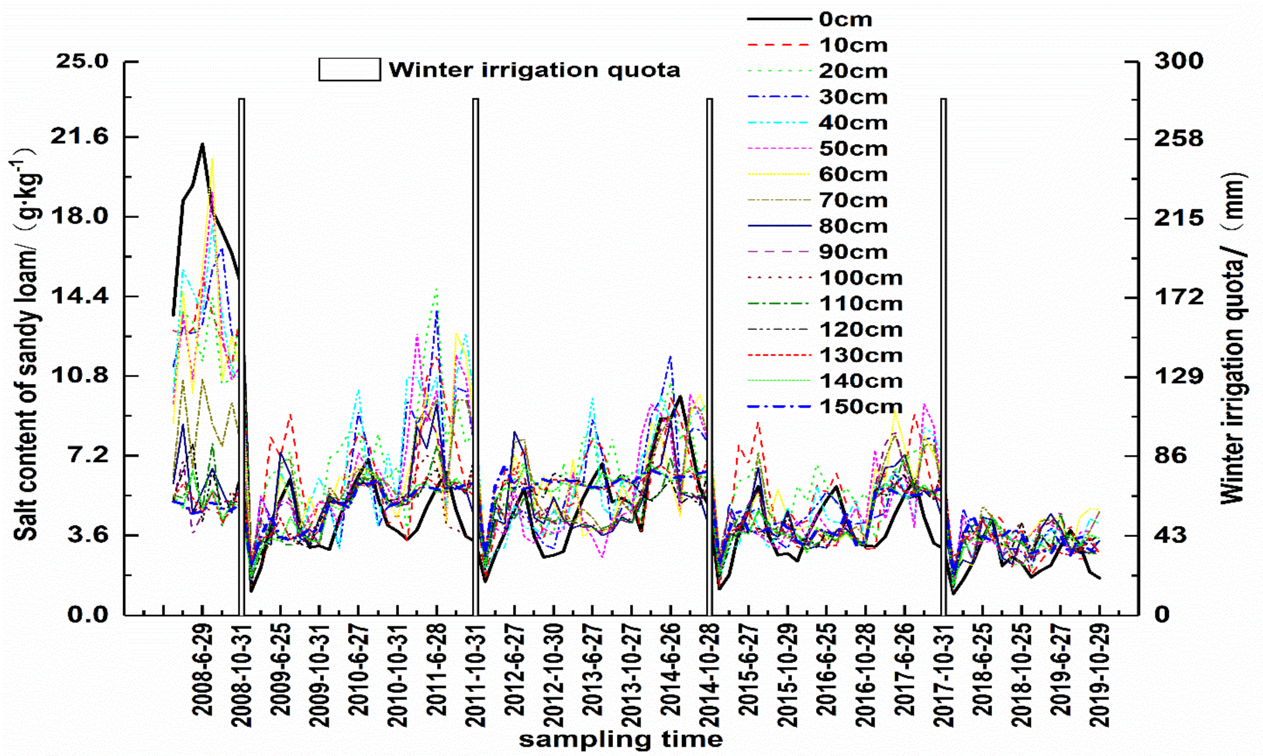


(a)



(b)

Figure 4. *Cont*.



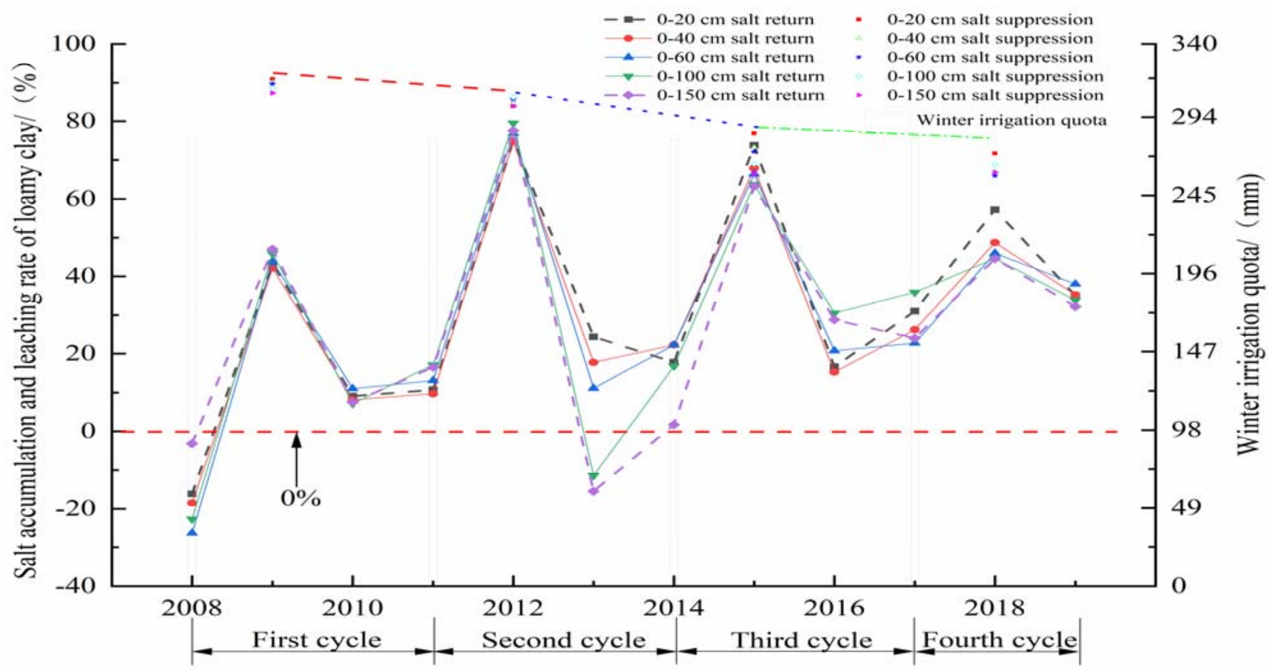
(**c**)

Figure 4. The average salt content of each observation layer of different soil types. (**a**) Loamy clay; (**b**) loam; (**c**) sandy loam.

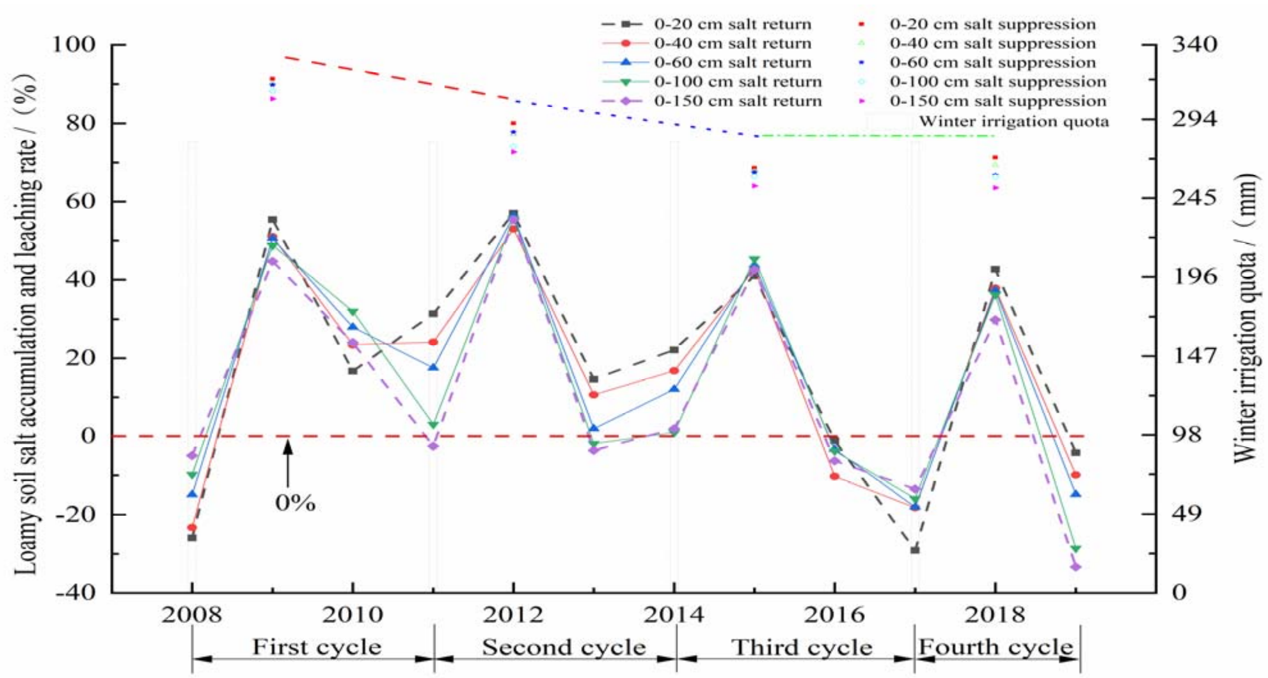
After winter irrigation, the average salt content of each observation layer decreased significantly and basically reached the non-salinized level. After cotton was planted in the next year, the salt return and drip irrigation interacted during the growth period. The salt content rose after three years of planting, which would stress cotton growth. The risk to cotton growth from soil salinity increased, and winter irrigation was required. The salinity of loamy clay and loam soil reached the non-salinized level after 10 and 7 years of drip irrigation under mulch, respectively. Sandy soil has poor water retention due to soil porosity, and salt is easily leached to lower layers during irrigation; however, when water evaporates, the salt is easily returned to the surface, resulting in drastic changes in salt content. This showed that the combination of drip irrigation during the growth period and periodic winter irrigation during the non-growth period effectively reduced the salt soil content, reduced the controllable range, and provided a suitable water and soil environment for crops. The model can be popularized and applied, but also according to the actual situation, the appropriate amount of washing water and washing interval should be selected. This can help the practical application of agriculture.

3.2. Effect of Cyclic Winter Irrigation on Soil Salt Return and Leaching Effect of Different Soil Salinities under Mulch Drip Irrigation

Periodic winter irrigation times expressed periodically: the interval between two winter irrigations is one cycle, and the period of 2008–2019 was divided into four cycles. The specific cycles result in different soil quality, measured in 0–20 cm, 0–40 cm, 0–60 cm, 0–100 cm, and 0–150 cm soil. See Figure 5 for the analysis of the effect of re-salting of soil tillage layers and leaching after winter irrigation.

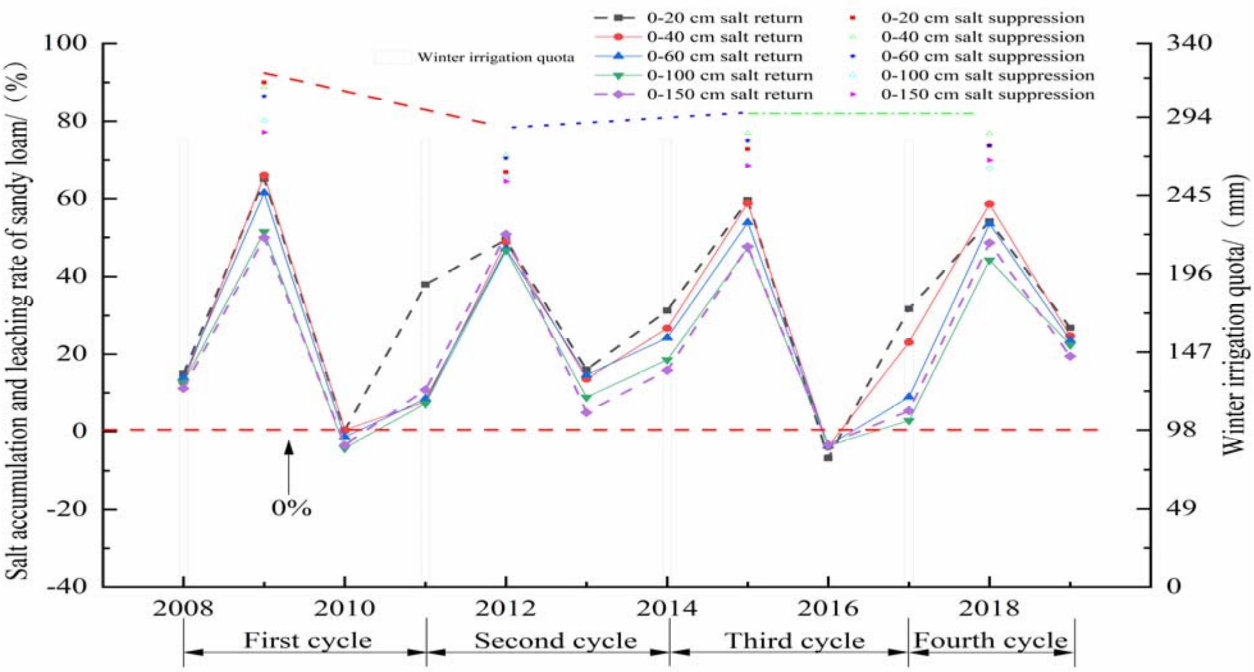


(**a**)



(**b**)

Figure 5. *Cont.*



(**c**)

Figure 5. Analysis of salt leaching effects of different soils and salt return from farming. (**a**) Loamy clay; (**b**) loam; (**c**) sandy loam.

Before winter irrigation in 2008, after the growth period, the total salt of the observation layers of the loamy clay and the loam showed desalination; the total salt of the observation layers of the sandy loam showed the phenomenon of salt return. In the first cycle, the SRR of each observation layer in the loamy clay and sandy loam soil increased significantly after winter irrigation. The winter irrigation caused the upper soil salinity to drop significantly, which played a role in suppressing salinity; the salt gradient of the upper layer having less salt and the lower layer having more affected the following year's cultivation. The continued tilling in the second year resulted in the upper layer showing no obvious salinity; in the third year, there was slight salinity in the observation layers, and thereafter, the second, third, and fourth cycles had similar changes.

After the first cycle of winter irrigation in loam soil, the SRR of each observation layer increased significantly, and the observation layers did not return to being saline in the second year of the growth period and were 0–20 cm and 0–40 cm in the third year; the other observation layers did not return to being saline. After that, the second, third, and fourth cycle changes were like those of loamy clay. However, there was no salinity in the observation layers during the third year of cultivation in the third cycle of the loam soil. This showed that the continued cultivation of soil redistributed salinity in each observation layer under the action of drip irrigation and also that it was reasonable to carry out periodic winter irrigation for three years of cultivation. The salinization of loamy clay and loam for 0–20 cm and sandy loam for 0–40 cm after winter irrigation was the most obvious, and the SRRs of different observation layers all exceeded 40%. Above the red line in the loam map indicates SRR > 0%, and below indicates SRR < 0%. The SRRs of observation layers were <0% in loamy clay for 0–100 cm and 0–150 cm in 2013 and all layers in loam soil in 2016, 2017, and 2019 observation layers and sandy soil in 2016, indicating that the cotton fields experienced a growth period. The total salt in each observation layer did not increase.

The desalination rate of four winter irrigations with different soil quality is indicated by a trend line. The desalination rates of the loamy clay, loam, and sandy loam observation layers in the four cycles exceeded 65.97%, 63.52%, and 64.48%, respectively. The desalination rate of each observation layer of loamy clay was the most significant, and the effect of winter irrigation on loam was the greatest. The desalination rate of each observation layer of loamy clay and loam showed an overall downward trend; the desalination rate of each observation layer in the first three cycles decreased significantly, and the desalination rate of each observation layer in the fourth cycle decreased slightly. The sandy loam soil desalination rate of each observation layer in the first cycle clearly decreased, and then, the salt return rate of each observation layer increased slightly. This was mainly because the water retention of sandy loam was worse than that of loamy clay and loam. The intense evaporation resulted in the salt content of the sandy loam increasing rapidly, and then, the evaporation of water left only the salt on the surface of the farmland.

3.3. Effect of Periodic Winter Irrigation in Cotton Fields with Different Soil Types on Survival Rate and Yield of Cotton under Mulch Drip Irrigation

Cotton survival rate and yield change are the final indicators to measure whether the combination of drip irrigation under mulch and periodic winter irrigation during the growth period is effective and reasonable. It is also an important indicator for evaluating the effect of this irrigation mode on soil salinity improvement and the sustainability of crops. See Figure 6 for the survival rate and yield changes of cotton in different soils.

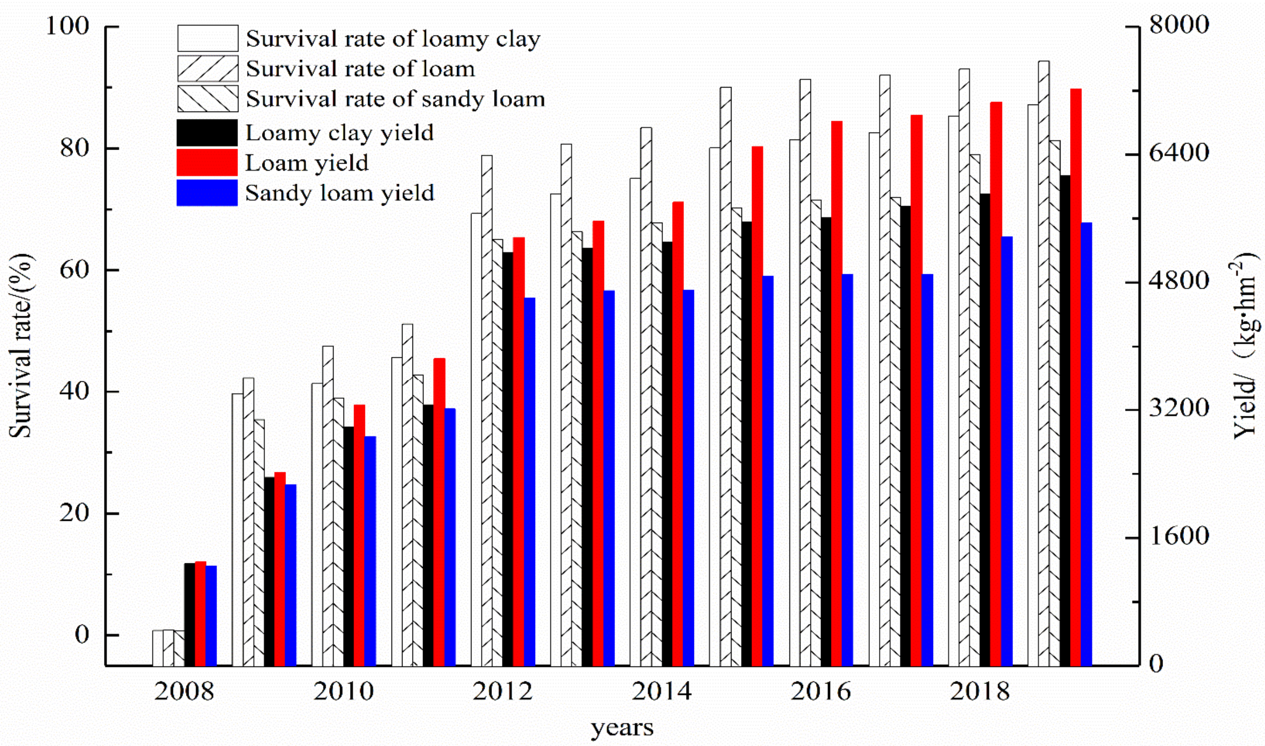


Figure 6. Changes in survival rate and yield of cotton in different soils.

The survival rate of cotton in cotton fields with different soil types was directly proportional to yield and was in the order loam > loamy clay > sandy loam, related to the relationship and regulation of soil texture and soil fertility. Before the first winter irrigation in 2008, the survival rate of cotton with different soil types was <0.92%, and yield was <1296.5 kg/hm^2; after the first winter irrigation in 2008, the survival rate and yield were ≥35.4% and ≥2264.8 kg·hm^{-2}, respectively, which increased from the previous year (≥34.47% and ≥967.8 kg·hm^{-2}). The survival rate and yield of cotton after the second winter irrigation in 2011 were ≥65.1% and ≥4602.6 kg·hm^{-2}, respectively; correspondingly, after the third winter irrigation in 2014, they were ≥70.2% and ≥4876.3 kg·hm^{-2}, and after the fourth winter irrigation in 2017, they were ≥79% and ≥5369.4 kg·hm^{-2}. The highest survival rate and yield in 2019 were 94.3% and 7216.8 kg·hm^{-2}, respectively. After five years of drip irrigation under mulch, the survival rate of cotton fields with different soil types exceeded 60%.

Periodic winter irrigation had a significant effect on the yield and survival rate of different soil cotton fields. The ANOVA results are summarized in Table 3. Loam soil has a significant impact on cotton field yield and survival rate ($p < 0.05$). Compared with sandy loam soil, loam soil had significantly greater cotton field yield and survival rate. There was no significant difference in yield and survival rate between loamy clay and loamy soil, showing that loamy clay and loamy soil were more suitable for planting cotton, and loamy soil was the most suitable.

Table 3. Significance analysis of yield and survival rate in the experimental area.

Soil Quality	Yield Survival	Rate
Loamy clay	4547.71 ab	63.42 ab
Loam	5170.47 a	70.47 a
Sandy loam	4097.93 b	57.59 b

Not having the same letter means that the treatment is significant. a and b are significant, but between a and ab, b and ab are not significant.

3.4. Economic Benefits of Periodic Winter Irrigation for the Experimental Site

Economic benefits depend on cotton field output, cotton seed unit price, and national policy subsidies. Annual expenditure has five components: land rent, purchase of agricultural materials, labor costs, machinery costs, and irrigation water costs. Among them, the cost of agricultural materials includes the purchase of cotton seeds, mulch, drip-irrigation tape, fertilizers, and pesticides; and labor costs include the cost of drip-irrigation facilities, seedling setting, tipping, weeding, spraying, and manual cotton picking. After 2017, cotton picking was mechanical. The cost of manual harvesting of cotton was included; the cost of machinery includes plowing, raking, sowing, cultivating, and transporting cotton; the irrigation water fee is generally the product of the irrigation quota and the water price, and the corresponding irrigation fee was added during winter irrigation. The annual income and expenditure of the experimental site was recorded in detail, and the annual income and expenditure ratio were calculated for the different soil types (Figure 7).

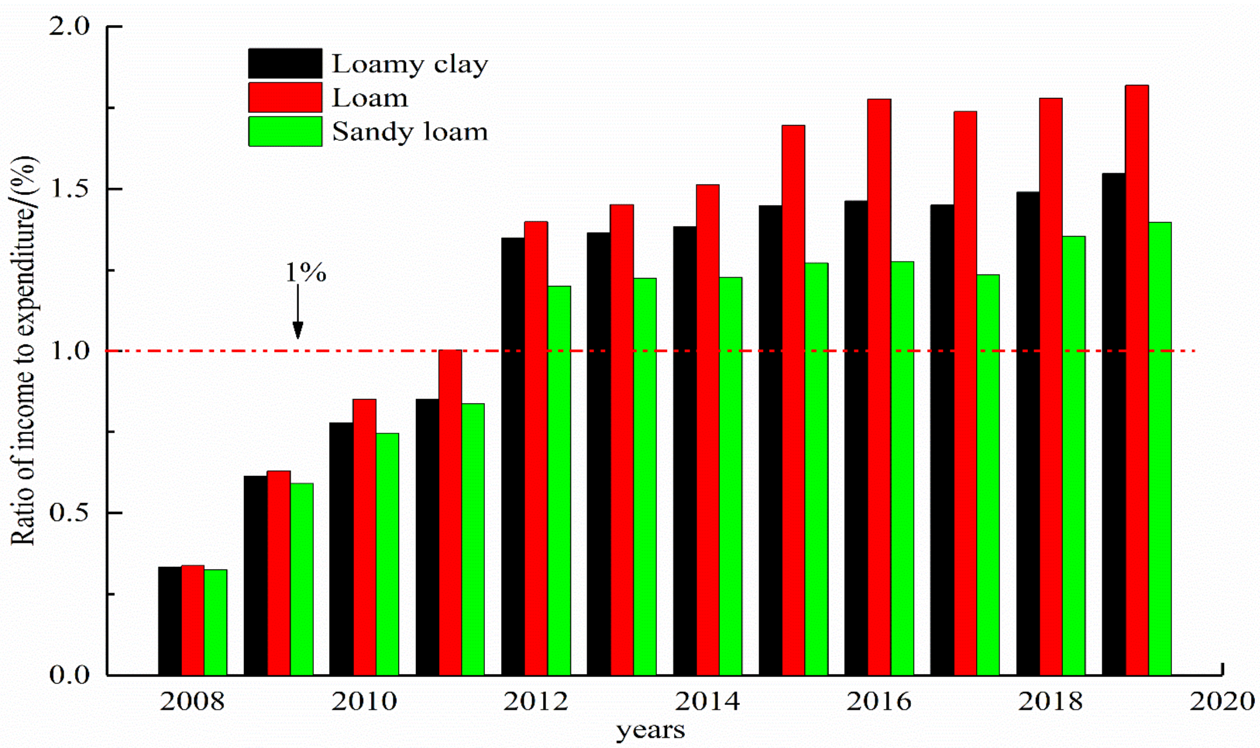


Figure 7. The income and expenditure ratio of different soil quality.

In Figure 7, above the red line represents the ratio of revenue and expenditure > 1%, and the following represents the ratio of revenue and expenditure < 1%. After two winter irrigations, following the fourth year of drip irrigation, the different soil budget ratios all exceeded 1%; after each winter irrigation, the soil budget ratios all increased slightly. As of 2019, the soil budget ratios all exceeded 1.39%, with a maximum of 1.82%. Compared with 2008, the revenue-to-expenditure ratio in 2019 increased by 1.09%, and the different soil budget ratios in order were medium loam > loamy clay > sandy loam. This was mainly due to the difference in soil porosity and fertilizer retention effects. The income/expenditure ratio exceeded 1%, which will not only improve the living standards of farmers and their enthusiasm for planting cotton but also showed that it was reasonable to combine drip irrigation under mulch during the growth period with periodic winter irrigation during the non-growth period.

4. Discussion

Based on existing research, according to the continuous monitoring of the typical oasis farmland in Xinjiang for up to 12 years, drip irrigation under film in the local growth period combined with the non-growth period is regularly implemented every three years (winter irrigation 2800 $m^3{\cdot}hm^{-2}$). Theoretical analysis of the irrigation mode showed that this mode can effectively improve different soil saline-alkali land after 10 years of planting, seeing as the layer of the crop root zone is suitable due to low salinity, thus increasing cotton yield. The five northwestern provinces have different treatment times for saline-alkali land: autumn irrigation is an important measure in the Hetao area (the largest saline-alkali irrigation area in China), which often uses salt leaching and spring moisture preservation [12]; winter irrigation can significantly improve soil water and heat conditions and has a positive impact on alleviating the "spring drought" and promoting crop growth and development [42]. Through experimentation and numerical simulations, some scholars [32–34] found that a large winter irrigation of 3000 $m^3{\cdot}hm^{-2}$ was more beneficial to increase production and reduce soil salinity. The next year's output was also stable at more than 7000 $kg{\cdot}hm^{-2}$, consistent with the irrigation amount used in the present study—our conclusions on the yield of loam after four winter irrigations were basically the same. Yao [37] believed that the 200 mm of winter irrigation in 0–100 cm of sandy loam soil has the effect of leaching salt, with a salt-leaching rate of 7.26%, which is due to differences in region, climate, irrigation system, and irrigation water salinity. Most winter and spring irrigation studies did not include drip irrigation under mulch in the long-term effects of periodic winter irrigation on soil salinity of cotton fields. The present study included this with relatively good results. Future research will continue winter irrigation quotas and leaching years that can increase production and improve water-use efficiency for different soil types and provide theoretical support for the sustainable development of farmland in arid areas. However, this paper also has the following limitations: there is no control in the experimental treatment, and only the long-term effect of periodic winter irrigation on salinity is studied; only the irrigation method once every three years was discussed, and the long-term effect of different years and different irrigation amounts on the salt content were not discussed. At the same time, this also clarified the scientific problems that need to be further explored in this article.

Drip irrigation is local irrigation, there is no drainage, and no deep leakage occurs; the initial value of salinization is high, the climate is dry, and the salt travels with the water, leading to the threat of salt accumulation in long-term drip irrigation under film mulch. After four winter irrigations, the observation layers were generally maintained within a range suitable for crops. However, the issue of salt accumulation in drip irrigation under mulch has always been controversial. Wang [11] and Li [19] believed that drip irrigation under film mulch technology will not cause salt accumulation, and it will be reduced at the initial stage of use and then stabilized within a smaller range. However, Sun [12] and Zhang [43] believed that plastic film mulching inhibited soil evaporation and avoided the accumulation of soil salt on the soil surface under the film. However, bare land between films shows strong salt accumulation on the surface, and over the long term, this will cause salt accumulation in soil. Some scholars used brackish water for irrigation and found no significant increase in salinity [44,45], while high-frequency irrigation under film mulch can effectively control soil salinity [46]. When exploring the regularity of cyclical winter irrigation on farmland soil salinity, we found that the salinity returns of each observation layer after winter irrigation continued to increase in the following year, and the salinity return of each observation layer showed a decreasing trend when planted in the second year. The salt return of the observation layer generally had a slight upward trend. This was because winter irrigation drip irrigation with saline water and strong evaporation interacts dynamically, leading to changes in the degree of salinity in each soil layer during farming. Additionally, this also showed that three-year periodic winter irrigation was reasonable. Therefore, long-term use of drip irrigation technology under film was not the reason for soil salt accumulation. However, the salt in groundwater is also an important factor; some scholars have found that long-term use of drip irrigation under film mulch for farmland does lead to salt content exceeding the standard and even harming cotton growth. Similarly, there is no periodic winter irrigating salt in this article, and the soil salt distribution may be a unique situation, so it is necessary to continue scientific, standardized, and systematic research on the management and improvement of saline-alkali soil used to grow cotton.

Climate change is an important factor affecting the development of irrigation agriculture and the formation of native saline-alkali soil in Xinjiang, which has significant effects on groundwater level, soil, topography and crop yield. "Salt goes with water, water goes with salt retention;" this often causes this generation of salinization in irrigated agriculture, and the critical groundwater depth has a significant impact on it. The groundwater depth in the test site varied with seasons: it was shallow in spring and winter and deep in summer and autumn. Groundwater depth and climate change have significant impacts on water and salt, cotton survival rate, and yield of long-term drip irrigation farmland under mulch in Xinjiang oasis farmland ecosystem, and even these research factors will be another result. This indicates the complexity of the multi-year dynamic problem of salinity and requires more systematic observation and research [26]. This paper focuses on the effects of soil quality and winter irrigation on soil water and salt, cotton survival rate and yield, and temporarily does not focus on the effects of groundwater and climate change on the experiment. However, groundwater and climate change will be studied in the following studies to improve the experiment. The deficiency is that there is no research on the effects of groundwater level and climate change on farmland water and salt, cotton survival rate, and yield in growth period and non-growth period.

The salinity management of cotton fields in oases should not only strengthen research on irrigation systems during the growth period but should also address salt washing during the non-growing period to ensure the coordination of cotton production and soil habitat [47]. Drip irrigation under film mulch during the growth period combined with periodic winter irrigation during the non-growing period, after winter irrigation, showed that salinity clearly returned during farming in the growth period. With the increase in the number of winter irrigations, cotton fields are gradually improved from high-saline-alkaline soil to low-saline-alkaline soil. Salinity showed small fluctuations but at a low level, although salinity was not removed. This was because the land was in a natural dynamic balance before it was cultivated. The irrigation water source itself contained traces of salt and there was strong evaporation. Periodic winter irrigation redistributed salt in cotton fields and gradually produced a new balance.

5. Conclusions

This paper aims to study the long-term effects of periodic winter irrigation on salinity in cotton field. The long-term changes of salt content, desalination rate, survival rate, and yield in farmland were explored. It has played a promoting role in the utilization of water resources, the promotion of saline-alkali land, and the increase of cotton yield.

(1) For the 12-year growth period under film mulch drip irrigation combined with non-growth period cyclic winter irrigation in farmland of different soil types, the salinity status when planting began in 2008 was 6–60 $g \cdot kg^{-1}$, 10–65 $g \cdot kg^{-1}$, and 4–22 $g \cdot kg^{-1}$ for loamy clay, loam, and sandy loam, respectively. After the application of this model, soil salinity was basically stable at a lower level, with salinity of loamy clay, loam, and sandy loam less than 5.74 $g \cdot kg^{-1}$, 3 $g \cdot kg^{-1}$, and 4.76 $g \cdot kg^{-1}$, respectively.

(2) Before the winter irrigation in 2008, the observation layers of loamy clay and loam soil were desalinated during the growth period, and the observation layers of sandy loam soil were saline. After winter irrigation, the observation layers of different soil types had clearly lower salinity. In the second year, the observation layer was basically desalinated. In the third year, the soil returned to being slightly saline. The desalination rate of observation layers of loamy clay and loam showed a generally downward trend; the desalination rate of different observation layers of sandy loam fell significantly during the first cycle of winter irrigation and then increased slightly.

(3) The survival rate of cotton in fields of different soil types was directly proportional to yield, with the order loam > loamy clay > sandy loam. After the fourth winter irrigation in 2017, the survival rate and yield of cotton were $\geq$73.8% and $\geq$5106.9 $kg \cdot hm^{-2}$, respectively; the highest survival rate and yield in 2019 were 94% and 7100.2 $kg \cdot hm^{-2}$, respectively. After five years of drip irrigation under film mulch, the survival rate of cotton exceeded 60% for the different soil types. After four years of planting, the income-to-expenditure ratio of different soil types exceeded 1% and increased by 1.09% in 2019 compared with 2008.

Author Contributions: Conceptualization, J.F., G.W. and H.L.; data curation, J.F.; formal analysis, J.F.; funding acquisition, H.L. and G.W.; investigation, J.F.; methodology, R.T.; project administration, H.L. and G.W.; resources, J.F.; software, J.F.; supervision, M.C.; validation, M.C., Z.B. and T.H.; visualization, R.T. and Z.B.; writing—original draft, J.F.; writing—review and editing, H.L. and G.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (52069026), XPCC International Science and Technology Cooperation Project (2021BC003), Southern Xinjiang Key Industry Innovation and Development Support Plan Project (2020DB001).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The anonymous reviewers and the editor are thanked for providing insightful and detailed reviews that greatly improved the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Shi, Y.; Tang, H.; Wang, H.; Gao, Z.; Wang, L.; Zhang, H.; Liu, H.; Luo, Q.; Wang, L.; Xi, B.; et al. Research on Key Strategic Issues of Agricultural Resource and Environment in China. *Strateg. Study CAE* **2018**, *20*, 1–8. [CrossRef]
2. Tan, M.; Zheng, L. Increase in economic efficiency of water use caused by crop structure adjustment in arid areas. *J. Environ. Manag.* **2019**, *230*, 386–391. [CrossRef] [PubMed]
3. Qin, Z.; Ning, X. The Development Trend and Policy Optimization of China's Cotton Industry since China's Accession into WTO. *Reform* **2020**, *9*, 104–117.
4. Himanshu, S.K.; Fan, Y.; Ale, S.; Bordovsky, J. Simulated efficient growth-stage-based deficit irrigation strategies for maximizing cotton yield, crop water productivity and net returns. *Agric. Water Manag.* **2021**, *250*, 106840. [CrossRef]
5. Tian, C.; Mai, W.; Zhao, Z. Study on key technologies of ecological management of saline alkali land in arid area of Xinjiang. *Acta Ecol. Sin.* **2016**, *3636*, 7064–7068.
6. Xu, F.P.; Li, Y.K.; Ren, S.M. Investigation and discussion of drip irrigation under mulch in Xinjiang Uygur Autonomous Region. *Trans. Chin. Soc. Agric. Eng.* **2003**, *19*, 25–27.
7. Marinari, S.; Mancinelli, R.; Brunetti, P.; Campiglia, E. Soil quality, microbial functions and tomato yield under cover crop mulching in the Mediterranean environment. *Soil Tillage Res.* **2015**, *145*, 20–28. [CrossRef]

8. Zong, R.; Wang, Z.; Wu, Q.; Guo, L.; Lin, H. Characteristics of carbon emissions in cotton fields under mulched drip irrigation. *Agric. Water Manag.* **2020**, *231*, 105992. [CrossRef]
9. Chen, W.; Jin, M.; Ferre, T.P.A.; Liu, Y.; Xian, Y.; Shan, T.; Ping, X. Spatial distribution of soil moisture, soil salinity, and root density beneath a cotton field under mulched drip irrigation with brackish and fresh water. *Field Crop. Res.* **2018**, *215*, 207–221. [CrossRef]
10. O'Loughlin, J.; Finnan, J.; McDonnell, K. Accelerating early growth in miscanthus with the application of plastic mulch film. *Biomass Bioenergy* **2017**, *100*, 52–61. [CrossRef]
11. Wang, Z.; Yang, P.; Zheng, X.; He, X.; Zhang, J.; Li, W. Soil salinity changes of root zone and arable in cotton field with drip irrigation under mulch for different years. *Trans. Chin. Soc. Agric. Eng.* **2014**, *30*, 90–99.
12. Sun, G.; Qu, Z.; Du, B.; Ren, Z.; Liu, A. Water-heat-salt effects of mulched drip irrigation maize with different irrigation scheduling in Hetao Irrigation District. *Trans. Chin. Soc. Agric. Eng.* **2017**, *33*, 144–152.
13. Wang, Z.; Yang, B.; Xie, X.; Wang, Z.; Yang, H.; Dong, X. Effects of different irrigation regimes of drip irrigation under plastic film on sugar beet yield and water use efficiency. *Trans. Chin. Soc. Agric. Eng.* **2019**, *35*, 158–166.
14. Li, X.; Tian, D.; Guo, K.; Xu, B.; Zhao, S. Influence of mulch drip irrigation on wheat root distribution characteristics. *J. Drain. Irrig. Mach. Eng.* **2016**, *34*, 545–552. [CrossRef]
15. Zhou, S.; Li, F.; Zhang, H. Effect of Regulated Deficit Irrigation on Potato under-Mulched Drip Irrigation. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *615*, 12104. [CrossRef]
16. Shen, D.; Zhang, G.; Xie, R.; Ming, B.; Hou, P.; Xue, J.; Li, S.; Wang, K. Improvement in Photosynthetic Rate and Grain Yield in Super-High-Yield Maize (*Zea mays* L.) by Optimizing Irrigation Interval under Mulch Drip Irrigation. *Agronomy* **2020**, *10*, 1778. [CrossRef]
17. Yang, G.; Li, F.; Tian, L.; He, X.; Gao, Y.; Wang, Z.; Ren, F. Soil physicochemical properties and cotton (*Gossypium hirsutum* L.) yield under brackish water mulched drip irrigation. *Soil Tillage Res.* **2020**, *199*, 104592. [CrossRef]
18. He, H.; Wang, Z.; Guo, L.; Zheng, X.; Zhang, J.; Li, W.; Fan, B. Distribution characteristics of residual film over a cotton field under long-term film mulching and drip irrigation in an oasis agroecosystem. *Soil Tillage Res.* **2018**, *180*, 194–203. [CrossRef]
19. Li, M.; Liu, H.; Zheng, X. Spatiotemporal variation for soil salinity of field land under long-term mulched drip irrigation. *Trans. Chin. Soc. Agric. Eng.* **2012**, *28*, 82–87.
20. Li, K.; Liu, H.; He, X.; Li, X. Simulation of Water and Salt Transport in Soil under Pipe Drainage and Drip Irrigation Conditions in Xinjiang. *Water* **2019**, *11*, 2456. [CrossRef]
21. Luo, T.; Ren, W.; Xie, C. Necessity and feasibility of biotic improving the saline and alkaline land in Xinjiang. *Arid Zone Res.* **2001**, *18*, 46–48.
22. Guo, X.; Lan, Y.; Xu, L.; Yin, D.; Li, H.; Qian, Y.; Zhang, G.; Lü, Y. Effects of nitrogen application rate and hill density on rice yield and nitrogen utilization in sodic saline-alkaline paddy fields. *J. Integr. Agric.* **2021**, *20*, 540–553. [CrossRef]
23. Burt, C.; Isbell, B.; Burt, L. Long-Term Salinity Buildup on Drip/Micro Irrigated Trees in California. Presented at IA Technical Conference, San Diego, CA, USA, 18 November 2003.
24. Majumdar, A.; Upadhyay, M.K.; Kumar, J.S.; Sheena; Barla, A.; Srivastava, S.; Jaiswal, M.K.; Bose, S. Ultra-structure alteration via enhanced silicon uptake in arsenic stressed rice cultivars under intermittent irrigation practices in Bengal delta basin. *Ecotoxicol. Environ. Saf.* **2019**, *180*, 770–779. [CrossRef]
25. Peng, Z.; Wu, J.; Huang, J. Impact of intermittent infiltration on solute leaching efficiency in soil. *Trans. Chin. Soc. Agric. Eng.* **2012**, *28*, 128–134.
26. Letey, J.; Feng, G.L. Dynamic versus steady-state approaches to evaluate irrigation management of saline waters. *Agric. Water Manag.* **2007**, *91*, 1–10. [CrossRef]
27. AL-Mansori, N.J. Study the Effect of Intermittent and Continuous Ponding Depths by Using Different Heads to Leach Water. *J. Univ. Babylon Eng. Sci.* **2018**, *26*, 105–114.
28. Mermoud, A.; Tamini, T.D.; Yacouba, H. Impacts of different irrigation schedules on the water balance components of an onion crop in a semi-arid zone. *Agric. Water Manag.* **2005**, *77*, 282–295. [CrossRef]
29. Qadir, M.; Ghafoor, A.; Murtaza, G. Amelioration strategies for saline soils: A review. *Land Degrad. Dev.* **2000**, *11*, 501–521. [CrossRef]
30. Phocaides, A. *Handbook on Pressurized Irrigation Techniques*; Food and Agriculture Organization of The United Nations: Rome, Italy, 2000.
31. Chen, X.Q.; Wang, Z.H.; He, X.L.; Li, W.H.; Jiang, G.J. Effects of Winter Irrigation Method on Soil Moisture, Temperature Distribution in Cotton Fields of North Salt and Xinjiang. *J. Soil Water Conserv.* **2014**, *28*, 132–137.
32. Zhao, B.; Wang, Z.; Li, W. Effects of winter drip irrigation mode and quota on water and salt distribution in cotton field soil and cotton growth next year in northern Xinjiang. *Trans. Chin. Soc. Agric. Eng.* **2016**, *32*, 139–148.
33. Wang, C.; Wang, Q.; Liu, J.; Su, L.; Shan, Y.; Zhuang, L. Effects of mineralization of irrigation water and soil salinity on cotton emergence rate in Southern Xinjiang Uygur Autonomous Region of China. *Trans. Chin. Soc. Agric. Eng.* **2010**, *26*, 28–33.
34. He, P.; Zhang, F.; Fan, J.; Ho, X.; Liu, X.; Zhang, Y.; Xue, Z. Effects of soil moisture regulation on growth, quality and water use of cotton under drip irrigation in Southern Xinjiang. *Agric. Res. Arid Areas* **2020**, *38*, 39–46.
35. Bing, H.; He, P.; Zhang, Y. Cyclic freeze-thaw as a mechanism for water and salt migration in soil. *Environ. Earth Sci.* **2015**, *74*, 675–681. [CrossRef]

36. Hu, H.C.; Tian, F.Q.; Zhang, Z.; Yang, P.J.; Ni, G.H.; Li, B. Soil salt leaching in non-growth period and salinity dynamics under mulched drip irrigation in arid area. *J. Hydraul. Eng.* **2015**, *46*, 1037–1046.
37. Yao, B.; Li, G.; Wang, F. Effects of winter irrigation and soil surface mulching during freezing-thawing period on soil water-heat-salt for cotton fields in south Xinjiang. *Trans. Chin. Soc. Agric. Eng.* **2016**, *32*, 114–120.
38. Xinjiang Uygur Autonomous Region Bureau of Statistics, Xinjiang Survey Team. N.B. of S. Statistical Communiqué on the National Economic and Social Development of the Xinjiang Uygur Autonomous Region in 2019. Xinjiang Dly. 005. Available online: http://tjj.xinjiang.gov.cn/tjj/tjgn/202006/06087bf9aeb04c4eb518627b5ee028be.shtml (accessed on 1 April 2020).
39. Shi, H.; Li, R.; Yang, S. *Theoretical Research on Water, Heat and Salt Transfer of Salinized Soil and Water-Saving Irrigation*; China Water Conservancy and Hydropower Press: Beijing, China, 2011.
40. Liu, M.; Yang, J.; Li, X.; Liu, G.; Yu, M.; Wang, J. Effects of drip irrigation strategy on cotton root distribution and water use efficiency. *Trans. Chin. Soc. Agric. Eng.* **2012**, *28*, 98–105.
41. He, X.L.; Liu, H.G.; Ye, J.W.; Yang, G.; Li, M.S.; Gong, P.; Aimaiti, A. Comparative investigation on soil salinity leaching under subsurface drainage and ditch drainage in Xinjiang arid region. *Int. J. Agric. Biol. Eng.* **2016**, *9*, 109–118.
42. Li, J.; He, Z.; Chen, L.; Lin, P.; Zhu, X.; Fang, S.; Zhao, M.; Tian, Q. Effects of winter irrigation on soil hydro-thermal features in desert oasis farmland in arid area during freezing and thawing period. *Trans. Chin. Soc. Agric. Eng.* **2018**, *34*, 105–112.
43. Zhang, W.; Lü, X.; Li, L.; Liu, J.; Sun, Z.; Zhang, X.; Yang, Z. Salt transfer law for cotton field with drip irrigation under the plastic mulch in Xinjiang Region. *Trans. Chin. Soc. Agric. Eng.* **2008**, *24*, 15–19.
44. Wan, S.; Kang, Y.; Wang, D.; Liu, S.-P.; Feng, L.-P. Effect of drip irrigation with saline water on tomato (*Lycopersicon esculentum* Mill) yield and water use in semi-humid area. *Agric. Water Manag.* **2007**, *90*, 63–74. [CrossRef]
45. Kang, Y.; Chen, M.; Wan, S. Effects of drip irrigation with saline water on waxy maize (*Zea mays* L. var. ceratina Kulesh) in North China Plain. *Agric. Water Manag.* **2010**, *97*, 1303–1309. [CrossRef]
46. Liu, M.; Yang, J.; Li, X.; Liu, G.; Yu, M.; Wang, J. Distribution and dynamics of soil water and salt under different drip irrigation regimes in Northwest China. *Irrig. Sci.* **2013**, *31*, 675–688. [CrossRef]
47. He, Y.; Wang, B.; Wang, Z.; Jin, M. Study on irrigation scheduling of cotton under mulch drip irrigation with brackish water. *Trans. Chin. Soc. Agric. Eng.* **2010**, *26*, 14–20.