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Variation of soil temperature in cotton field covered with plastic film under saline water irrigation

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ABSTRACT

Changes of soil temperature in cotton field covered with plastic film under saline water irrigation were investigated by plot trial. Results showed that saline water irrigation produced a certain influence on soil temperature by changing ground coverage. Soil temperature in the rows with film mulching (RFM) was higher than that in the rows without film mulching (RNFM), especially at seedling stage and in the 5~10 cm soil layer. The daily variation of soil temperature in different positions fitted sinusoidal curve approximately. With the increase in soil depth, the process of soil temperature change became steady, and the appearance time of peak value delayed. During the growing season, the average daily soil temperature in different soil depths in RFM and RNFM was linear positively related to the near-surface air temperature, and the correlation coefficients reached extremely significant level (P<0.01). For one day, if the time-lag effect between soil temperature and air temperature was corrected, the relationship between the soil temperature in different soil depths and the near-surface air temperature gave a good fitted to linear regression equations, and the correlation coefficients reached a significant level (P<0.05). The experimental results provided a theoretical basis for the building of water-heat-salt transfer model and the regulation of water-salt distribution.

KEYWORDS

Saline water; Plastic mulching; Cotton field; Soil temperature; Near-surface air temperature.

INTRODUCTION

Soil temperature, one of the main factors in farmland ecosystem, is an important variable governing plant development and variation of soil environment either directly or indirectly[1,6,12,14]. Consequently, it is of important for the tillage and cultivation techniques to determine the variation process of soil temperature. Soil temperature is influenced by many factors, and effects of solar radiation[13], air temperature[9,11], ground coverage[2,8], soil moisture[4] and soil porosity[3] on soil temperature have been investigated by many researchers, and the corresponding characteristics of soil temperature were presented. It could be concluded that agricultural irrigation (such as irrigation methods and irrigation water quality) not only can affect soil physical and chemical properties and crop growth, but also have effect on soil temperature. Soil temperature, in turn, is also one of the factors affecting irrigation decision and management.

In recent years, with the increasingly perilous situation of water resource shortages, as well as the struggle for land and water between grain crops and cotton in China, it is imperative to develop saline irrigation technology for cotton. Knowledge about how to regulate the distribution of moisture and salt in cotton root zone is the determining factor in restricting the security of saline water irrigation. Some researches indicated that soil temperature is an important factor to influence water-salt transport and salt-tolerant of cotton[5,10]. In addition, plastic film mulching technology is widely applied in the most cotton regions of China. Film mulching changes the temporal-spatial distribution of soil temperature, which causes a significance difference between the rows with film mulching (RFM) and the rows without film mulching (RNFM). Therefore, the objectives of this research were to investigate changes in soil temperature at different points in cotton field with film mulching under saline water irrigation, and to reveal the response of soil temperature to the near-surface air temperature.

MATERIALS AND METHODS

Experimental site

Field experiments were conducted at the Hengshui Experimental Station (37°44′ N, 115°47′ E, elevation 21.0 m) during the crop-growing season from April to November in 2012. The station is affiliated with the Dry Land Farming Institute of the Hebei Academy of Agricultural and Forestry Sciences, situated in the middle of Hebei Plain. The annual mean temperature is 12.8 °C, annual sunshine duration is 2509 h, annual frost-free days are 188, average annual precipitation is 500 mm, and the mean potential evaporation is 1785 mm. Groundwater TABLE is over 7 m. The experimental soil was loamy with mean bulk density of 1.44 g/cm^3, mean field capacity of 29% (gravitational content) in 0-100 cm profile. Soil available nitrogen (N), phosphorus (P) and potassium (K) contents were 76, 15 and 112 mg/kg, respectively, and soil organic matter content was 11.5 g/kg. Soil salt content was between 0.1% and 0.2% (gravitational content) in 0-40 cm profile. The overexploitation of deep fresh groundwater was serious in the region, however, the abundant shallow ground brackish water (salinity 2-5 g/L) had not been exploited and used.

Experimental design

Based on the salinity of irrigation water, the field experiments were designed and settled by randomized complete block design with four treatments and four replications. The irrigation water salinity of four treatments were 1.28 (S1), 5.41(S2), 8.82 (S3) and 12.39 (S4) dS/m, respectively. Local groundwater (fresh water) with an ECiw of 1.28 dS/m was used in S1 as control treatment. Salinity levels from S2 to S4 treatments were achieved by adding NaCl to locally pumped ground water. Irrigation method of all treatments was the border irrigation. For each treatment, the lower limit of irrigation during cotton growing period was 65% of field capacity, and the irrigation quota was 75 mm.

Cotton (*Gossypium hirsutum* L. 'Jimian616') was planted in wide and narrow rows alternately. Cotton was sown on 3 May, and harvested on 8 November. The wide-row spacing, the narrow-row spacing, and the inter-plant spacing was 80, 50, and 30 cm respectively. Each replicate had a plot area of 6.6 m × 5.7 m. The narrow rows were covered with plastic film after sowing, and the ratio of bare land to mulching land was 1:1. Irrigation amount before sowing (27 April) was 50 mm and the supplemental irrigation of 75mm was applied at the budding stage (18 June). Weed control and other field management practices were kept the same for all the treatments and replicates. It should be noted that transplanting was carried out for seedling missing places on 18 days after sowing.

Measurements

Soil temperature, air temperature and humidity

Soil temperature in the 0-40 cm soil layer was measured using JL-04 soil temperature recorders (QingSheng, China) at 30 min intervals. The sensors were buried at the soil surface and 5, 10, 15, 20, 40 cm depth in the RFM and RNFM, respectively.

Air temperature and humidity at the height of 15 cm to the ground surface was measured using CSL2 Temperature and RH Probe (Campbell, USA), and the data were recorded using a CR1000 data logger (Campbell, USA) at 60 min intervals.

Soil moisture and salinity

Soil samples were collected from each plot every 10 days with an auger (3.0 cm in diameter and 15 cm high). In each plot, two sampling points were set at the midline of RFM and RNFM, respectively. All the sample depths were the same, i.e. 0–10, 10–20, 20–30 and 30–40 cm. Each soil sample was separated into two parts, which were put in plastic bag (air-dried and sieved through a 1 mm sieve, used for measuring soil salinity) and in aluminum box (drying at 105 ℃ and weighing, used for measuring soil water content), respectively. Soluble salt content was estimated using the water solution (water : soil = 5:1). The electric conductivity ,EC) value was determined using a DDS-307A conductivity meter (REX, Shanghai).

Leaf area index (LAI)

LAI of cotton was measured after emergence at 10 days interval during the whole growing season. Leaf length and leaf width were measured with a ruler, and leaf area was determined with following formula: leaf area = leaf length × leaf width × 0.84 ,Hong et al., 1984). LAI was set as the ratio of total leaf area to land area over an experimental plot ,Wu et al., 2010).

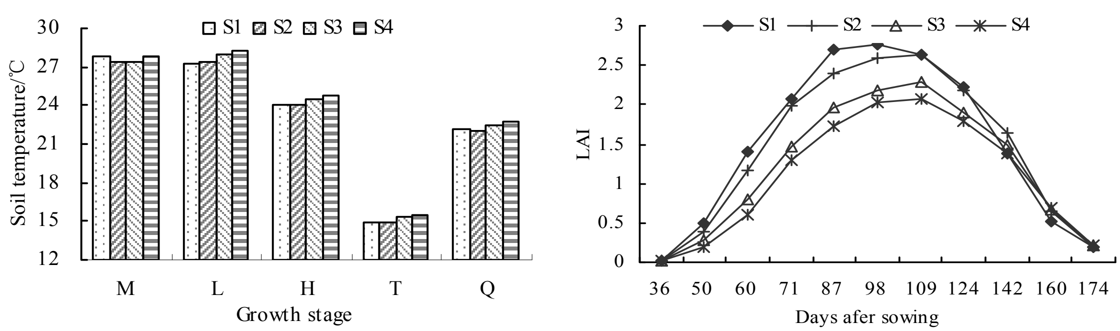
Statistical analysis

Data were processed and analyzed using the DPS 12.5 software package.

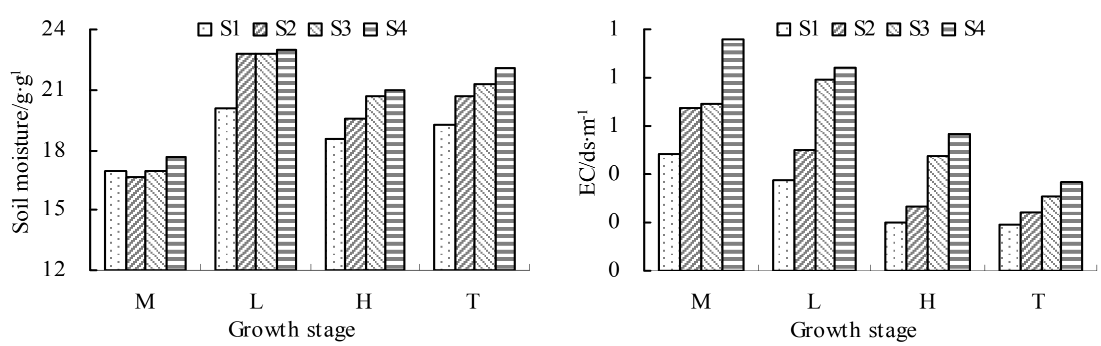
RESULTS AND DISCUSSION

Effects of irrigation water salinity on soil temperature, leaf area index, soil moisture and soil salinity

Changes of average daily soil temperature in the 5 cm soil layer (mean value of the rows with and without plastic film) under irrigation with different salinity contents were shown in Figure 1a. Saline water irrigation had certain influence on soil temperature, but not significant. The effect was more evident at the budding stage where soil temperature increased with the increase in irrigation water salinity. Compared to S1, average daily soil temperature in the 5 cm soil layer in S2, S3 and S4 was increased by 0.24, 0.71, and 1.01 ^{0}C, respectively. The mean value of soil temperature over the growing season was very close between S3 and S1; while the mean soil temperature was increased by 0.31 and 0.61 ^{0}C in S3 and S4 than S1, respectively. The differences in soil temperature between different treatments were closely related to the effects upon cotton growth and soil physicochemical characters of saline water irrigation. As an important parameter of cotton population status, leaf area index (LAI) was one of main factors influencing field microclimate. LAI was restrained by saline water irrigation, especially in the treatments of 8.82 ds/m and 12.39 ds/m (Figure 1b). In general, the bigger LAI was, the more coverage areas were and the more difficult solar radiation reached ground surface; then soil temperature was affected. Besides, there were significant differences in soil moisture (Figure 1c) and salinity (Figure 1d) between different treatments of salinity contents, which may be an important reason for the differences in soil temperature between different treatments.



(a) (b)



(b) (d)

Figure 1 : Effects of saline water irrigation on soil temperature (a), LAI (b), soil moisture (c), and soil salinity (d) of cotton field. M, seeding stage; L, bud stage; H, blooming and fruiting stage; T, boll opening stage; Q, whole growth stage.

Dynamics of soil temperature in cotton field with saline water irrigation

As the similar effects of plastic film on soil temperature in cotton field under saline water irrigation with different salinity contents, the treatment of 12.39 ds/m (S4) was presented for analyzing soil temperature dynamics at different sites in cotton field.

Dynamics of soil temperature during cotton growing season

Changes in average daily soil temperature in RFM and RNFM were similar at any growing stages of cotton (Figure 2). Soil temperature decreased with soil depth at the seedling, budding, and flowering stages, but increased at the boll opening stage, which was caused by solar radiation, air temperature and humidity, crop coverage, soil moisture, soil salinity and many other factors. In the same soil layer, due to the sunlight penetration and light intensity being improved by film mulching, soil temperature in RFM was higher than that in RNFM. The warming effects of film mulching were changed with cotton growing stage and soil depth.

The warming effects were more evident at the seedling stage than at the budding stage, but least obvious at the flowering stage. During the four growing stages of cotton, average daily soil temperature in the depth of 0-40 cm in RFM was enhanced by 2.54, 1.54, 0.34 and 0.58 ^{0}C than in RNFM, respectively. Perhaps for two reasons: first, solar radiation at the soil surface decreased with the increase in crop coverage; and second, the film degraded gradually.

In the soil layer of 0~40 cm, the warming effects of film mulching increased and then receded with the increase in soil depth. The largest increase in average daily temperature in RFM was observed at the soil depth of 5~10 cm, then was at the soil surface, and the smallest increase was at the 40 cm soil layer. The increase in soil temperature at different depths affected by film mulching in sequence from high to low was 5, 10, 0, 15, 20 and 40 cm. The amplitude of temperature increase was 6.84%、6.73%、5.41%、4.91%、3.54%, and 1.17%, respectively.

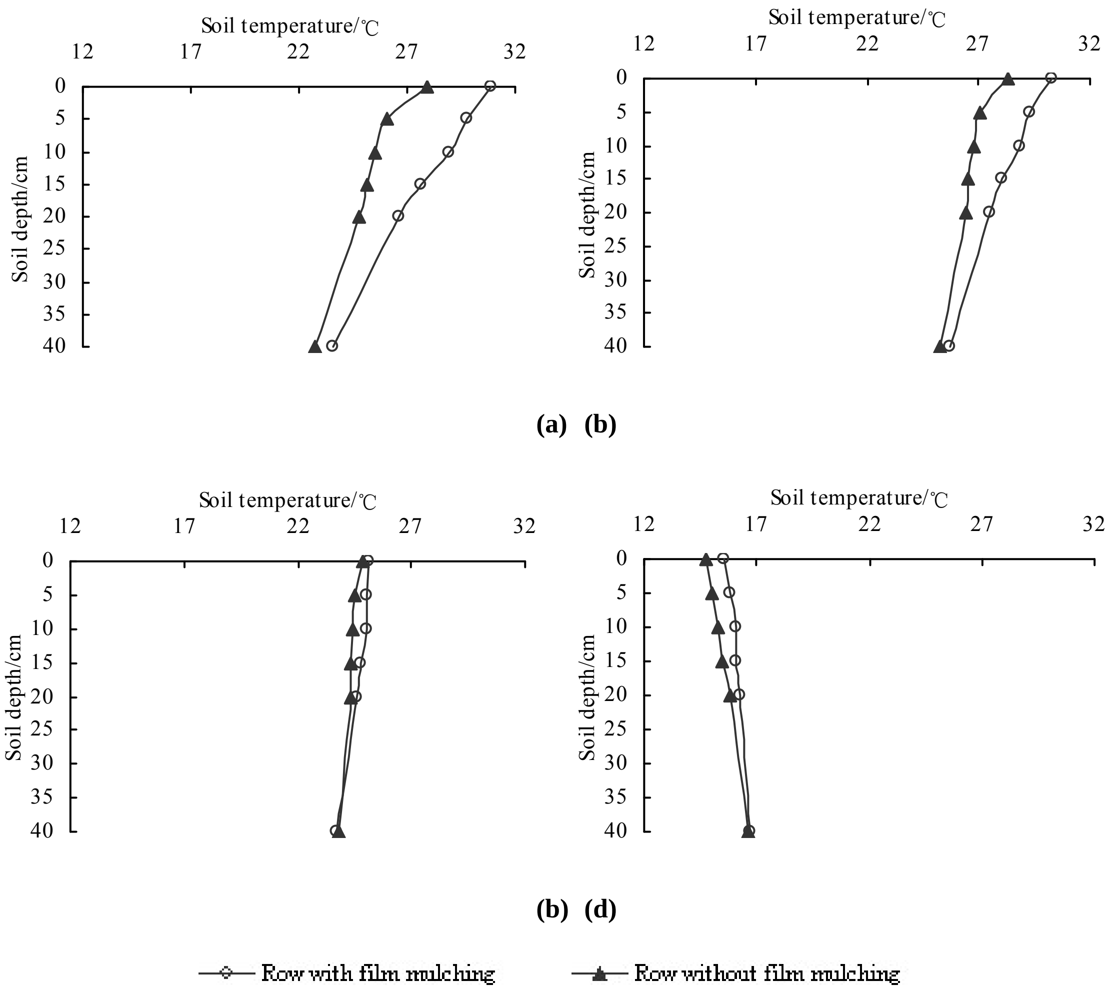


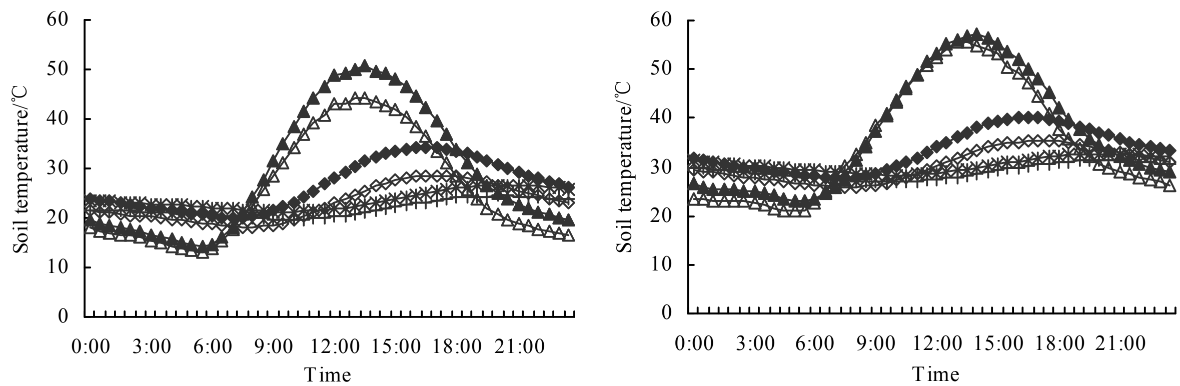
Figure 2 : Variations of average daily soil temperature in the seeding stage (a), bud stage (b), blooming and fruiting stage (c), and boll opening stage (d).

Diurnal variations of soil temperature in the typical periods

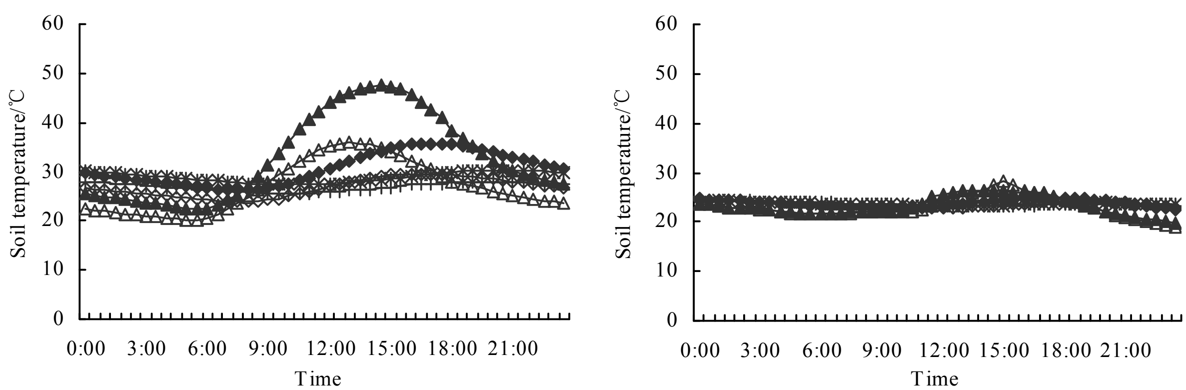
In order to evaluate the influence of film mulching upon soil temperature, daily variation of soil temperature at different sites in sunny day at the representative periods were analyzed. Figure 3 presented diurnal variations of soil temperature in depths of 0, 10, 20 cm in RFM and RNFM at the seedling stage (14 May), blooming and fruiting stage (21 August), the day before irrigation (17 June) and the day after irrigation at the budding stage (19 June).

In different cotton growing periods, daily variation of soil temperature at different depths fitted sinusoidal curve in the RFM and RNFM (Figure 3a and 3b). The minimum and maximum values of soil surface temperature appeared at 5:30 and 13:30 in the seedling stage. Under the film and outside the film, the daily change extent of soil surface temperature was 36.38 and 31.19 ^{0}C, respectively; the daily change extent of soil temperature at the depth of 10 cm and 20 cm was 14.28 and 10.33 ^{0}C, 5.26 and 4.79 ^{0}C, respectively. It was obvious that the fluctuation range of soil temperature reduced and became stable with the increase in soil depth, and the occurrence of peak temperature delayed. Statistical analyses suggested that the occurrence of the maximum soil temperature delayed 2~3 h with the depth of soil increased 10 cm. The diurnal variation of soil temperature at different depths in the RFM and RNFM reduced gradually with cotton growth processes, and the warming effects weakened as well.

Daily changes of soil temperature at different sites in the sunny day before and after irrigation were shown in Figure 3c and 3d. The warming effects of film mulching increased after irrigation, and the average warming rates increased by 17.54%, 4.46% and 2.57% at the soil surface, soil depth of 10 cm and 20 cm, respectively. Moreover, the daily change extent of soil temperature decreased after irrigation. Compared with one day before irrigation, the daily change extent of soil temperature at the depth of 0, 10, and 20 cm in RFM decreased by 26.57%, 24.11% and 31.17%, and in RNFM decreased by 54.44%, 39.73% and 43.75%, respectively.



(a) (b)



(b) (d)

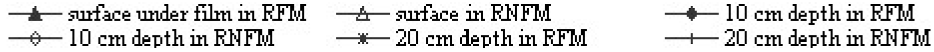


Figure 3 : Daily variation of soil temperature in cotton field covered with plastic film in the seeding stage (a), blooming and fruiting stage (b), one day before irrigation (c), and one day after irrigation (d).

Response of soil temperature to the near-surface air temperature

Soil temperature variation was a process that soil absorbed or released energy with the changes of solar radiation and atmospheric temperature. Under the conditions of crops grown, solar radiation reaching the ground and the near-surface air temperature were the direct factors to affect soil temperature. The response of soil temperature at different sites in cotton field in the treatment of 8.82 ds/m saline water to the near-surface air temperature was focused on in this study. Results indicated that, during cotton growing season (from 20 May to 8 November), the relationship between the daily average temperature in different soil depths and the near-surface air could be fitted with a positive linear equation, and the correlation coefficients were presented in TABLE 1. Therefore, the near-surface temperature can be used to stimulate daily average temperature at different soil depths.

For a certain day, the changes of soil temperature with the increase in soil depths were influence by a delayed effect. Chen et al. (2009) indicated that, every 5 cm increase in soil depth, the time when the maximum soil temperature appeared lagged about 1.2 h than that of peak air temperature. The results of 17 June were taken for an example. Taking no account of the lagging effect of soil temperature change, the correlation analysis were carried out between soil temperature in each depth and the near-surface temperature at the same time; the results were shown in TABLE.1. The correlation coefficient decreased with soil depth increasing. A significant positive correlation was found at the soil depths of 0, 5 and 10 cm; the correlation was not significant at the soil depths of 15 and 20 cm, but respectively negatively correlated at the soil depth of 40 cm. On basis of previous researches, changes of soil temperature lagged for 1 h with a 5 cm increase in soil depths, soil temperature in the soil depths of 0, 5, 10, 15, 20 and 40 cm was brought ahead of 0, 1, 2, 3, 4 and 8 h from 0:00. Then an analysis was carried out. It was observed that the highly significant positive correlation was found between the near-surface temperature and soil temperature after correction at different sites except that the site of 40 cm depth in the RNFM.

TABLE 1 : Correlation index of soil temperature in different positions responded to the near-surface air temperature

stages	positions	Soil depth/ cm					
		0	5	10	15	20	40
Whole growth stage	RFM	0.911**	0.927**	0934**	0.939**	0.940**	0.941**
	RNFM	0.952**	0.969**	0.967**	0.963**	0.961**	0.950**
17 June（Before correction）	RFM	0.948**	0.901**	0.758**	0.351	-0.020	-0.920**
	RNFM	0.911**	0.839**	0.653**	0.391	0.039	-0.630**
17 June（After correction）	RFM	0.948**	0.968**	0.966**	0.884**	0.804**	0.540**
	RNFM	0.911**	0.939**	0.925**	0.895**	0.822**	0.483*

Note: * means the correlation coefficients reach significant level (p<0.05), ** means the correlation coefficients reach extremely significant level (p<0.01), - means the correlation coefficients are negative.

CONCLUSIONS

(1) Irrigation with different salinity contents had effects on soil temperature by affecting leaf area index of cotton, soil water and salt content. However, the effects were not obvious.

(2) Soil temperature in RFM was higher than that in RNFM. During cotton growing season, the best warming effects of film mulching were found at the seedling stage and the worst at the blooming and fruiting stages. For the depth of soil layer, the largest warming range was in the depth of 5～10 cm, was the soil surface, and the soil depth of 40 cm was the smallest.

(3) The daily change tendency of soil temperature at different depths in RFM and RNFM was consistent. The fluctuation range and appearing time of the maximum value were reduced or delayed with the increase in soil depth. By comparing daily variation features of soil temperature before and after irrigation, the warming effects of film mulching were found to be enhanced after irrigation, while the variation range of soil temperature decreased.

(4) Daily average temperature in each soil depth and the near-surface air can be fitted with an positive linear equation. The response of soil temperature to the near-surface temperature has a time lagging effect with the increase in soil depth; they were fitted directly, and the correlation coefficient reduced with the increase in soil depth. According to the principle that every 5 cm increase in soil depth, the soil temperature delayed 1 h, soil temperature in each layer was forward and then develop a regression equation. The correlation coefficient was highly improved and reached a significant positive correlation level.

(5) There are many factors that affected the distribution and variation of soil temperature under the condition of saline water irrigation. The paper systematically described the dynamics of soil temperature in cotton field with film mulching. The quantitative relationship between soil temperature and the influencing factors, especially the coupling effects of water-heat and salt-heat remained to be studied in the future.

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