Xiaojun et al., Irrigat Drainage Sys Eng 2016, 5:2
DOI: 10.4172/2168-9768.1000160

Irrigation & Drainage Systems Engineering

Research Article Open Access

Study on Optimal Irrigation Index of Cotton with Drip Irrigation under Film Mulching based on Pan Evaporation

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Abstract

The objective of this paper is to find a simple and efficient drip irrigation schedule for cotton under film mulching using a homemade evaporation pan with a diameter of 60 cm. A field experiment was conducted to study the responses of cotton growth, seed cotton yield, water consumption and water use efficiency to drip irrigation amounts of 0.5 Ep (pan evaporation), 0.7 Ep and 1.0 Ep at the Irrigation Experiment Station of the Water-conservancy Bureau in Xinjiang Production and Construction Corps in Urumqi, Xinjiang province during the cotton growing seasons of 2007 and 2009. The feasibility of the drip irrigation scheme based on surface water evaporation by using a homemade evaporation pan was analyzed. The results showed that continuous water deficit at the bud and boll stages (irrigation quota equal to 0.5 Ep) produced negative effects on cotton growth, seed cotton yield and the water consumption process during the entire cotton growth period with drip irrigation under mulching compared to the sufficient irrigation treatment (irrigation quota equal to 1.0 Ep); the effect of timely and appropriate water deficit during the bud and boll stages (irrigation quota equal to 0.7 Ep and 0.5 Ep, respectively) on seed cotton yield was not significant; 22.78%~24.88% of the irrigation water was saved, while irrigation water use efficiency was improved by 27.94%~34.85%. It is suggested that the irrigation model with light water deficit during bud emergence (irrigation quota equal to 0.7 Ep), severe water deficit at the late flowering and boll stage (irrigation quota equal to 0.5 Ep), and sufficient water supply at the early flowering and boll stage (irrigation quota equal to1.0 Ep) is a convenient, high-quality, efficient drip irrigation pattern that can be used as a suitable irrigation approach to cotton production with drip irrigation under film mulching in Xinjiang.

Keywords: Drip irrigation under film mulching; Surface water evaporation; Water use efficiency (WUE)

Introduction

The abundant light, heat resources and diversity of the inland desert climate of Xinjiang provide a unique natural ecological environment for high yields and high quality cotton. With the agricultural planting structure adjustment, the Xinjiang cotton district has been China's largest economic district with cotton planting areas and the lint yield ranks the first in China. Cotton production has also been one of the important industries for the local economic development [1,2]. The Xinjiang cotton district is one of the typical irrigated agriculture production areas with little rainfall, and a large evaporation to rainfall ratio. The water needed for cotton growth is mainly obtained from irrigation, in which the water supply resources are not able to meet the water demand. Consequently, with the expansion of irrigated areas and the rapid development of socio-economic, industrial and agricultural production, a more severe water shortage situation confronts the cotton-growing region in Xinjiang. Hence, the efficient use of limited water resources has become one of the important issues facing the cotton production district. Found that water consumption is approximately 450 mm during the entire growth period for cotton high yield in Xinjiang under drip irrigation [3,4]; the average annual precipitation for many years has been less than 200 mm. This has very important implications for the efficient use of limited agriculture water resources, improvement of cotton quality and to achieve the goals of water-saving, high yield, and high efficiency, mainly through scientific irrigation method that can regulate soil water content.

Drip irrigation technology with the advantages of water-saving, high quality and high yield has been promoted and applied to cotton production in Xinjiang, somewhat alleviating the constraints of water supply and demand for cotton production. Drip irrigation under film mulching technology is a combination of the advanced drip irrigation for shallow frequency irrigation and mulching plant cultivation techniques. This is not only prevent deep percolation of irrigation water but also results in a significant reduction in the invalid evaporation between plants and surface soil, simultaneously contributing to increasing of the soil moisture storage, soil temperature and improving the crop hydrothermal environment. The adoption of advanced water-saving irrigation technologies and the development of rational irrigation schemes are required to protect crop yields, save water resources and improve water use efficiency. A number of studies have been conducted on drip tape laying [5,6], emitter discharge rate [7], crop growth [8-10], and yield and quality [11-13] with drip irrigation; these studies propose the corresponding irrigation index [2,14] to further improve water use efficiency of cotton soil under drip irrigation from the beginning of 1990s. However, most of the determinants of these indicators are needed to monitor soil moisture and cotton growth parameters. The measurement and control of these parameter indicators require professional operations and a higher level of theory and practice, which is difficult for ordinary cotton farmers in the Xinjiang cotton production area to master and use.

There is a strong relationship between pan evaporation and ET_0 [15]. A number of studies both at home and abroad investigated

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Received May 12, 2016; **Accepted** June 02, 2016; **Published** June 10, 2016

Citation: Xiaojun S, Mingsi L, Jiyang Z, Zugui L, Guisen Y, et al. (2016) Study on Optimal Irrigation Index of Cotton with Drip Irrigation under Film Mulching based on Pan Evaporation. Irrigat Drainage Sys Eng 5: 160. doi:10.4172/2168-9768.1000160

the relationship between pan surface evaporation and crop water consumption under different irrigation conditions [16-20] to develop a scientific irrigation system. Experimental research on A Standard evaporating pan adopted outside China is more common [21-23]. Conversely, the price of the Class A evaporation pan is relatively high and it has specific installation requirements, making it difficult to promote and apply in large areas in developing countries. In this study, field trials during two growing seasons investigated the response of cotton growth, yield and water use efficiency to different irrigation regimes (as different pan coefficients for guiding irrigation). This approach is based on the results of field experiments and will propose a simple and convenient operation and a "fool" water-saving irrigation index for the farmers, which makes the traditional water management model "see the day", "see the ground", and "see crops" for the cotton district in Xinjiang under drip irrigation scientifically achievable.

Materials and Methods

Experimental site

The field experiment was carried out in the Irrigation Experimental Station (43°59′N, 87°23′E) of Water-conservancy Bureau in Xinjiang Production and Construction Crops, Xinjiang, China, during the growth seasons of 2007 and 2009. The station is located in Xinjiang province, 30 km away from Urumqi, which is warm-temperate arid zone with a continental climate. According to statistics of meteorological data for 30 years from the Urumqi National Meteorological Station, average annual sunshine duration is 2864 h; annual accumulated temperatures are 3450℃ (≥10℃). Annual precipitation and potential evaporation are 190 mm and 1600 mm, respectively. The soil type of the experimental district is loamy soil, from 0 to 100 cm depth average soil bulk density is 1.51 g·cm^{-3}, the soil weight moisture capacity is 20.7%, water table is consistently 8 m below the ground.

Methods of cotton planting and fertilization

The cotton crops (Xin luzao 9) were planted on April 28, 2007, wholly emerged on May 6, harvested from September 14; and planted on May 2, 2009, wholly emerged on May 14, harvested from September 19. The planting were sowed at low soil moisture and watering at seedling stage. The cotton crops were planted in row spacing 20 cm + 45 cm + 20 cm (one tube controls 4 rows of cotton crop, (Figure 1), with plant spacing 11 cm. Two growing seasons were respectively applied with efficient manure of 150 kg·hm^{-2} (Phosphate, total nutrient content of N, P_2O_5 and K_2O are more than or equal to 60%; the total content of trace elements for Zn, B, Fe, Mn, etc. are more than or equal to 0.5%), and urea 450 kg hm^{-2} (Total nitrogen content is more than or equal to 46.4%) during the whole cotton growth. The fertilization through drip irrigation systems was divided into five portion and each time the amount of urea and efficient fertilizer were 90 kg hm^{-2} and 30 kg hm^{-2} (pure N, P_2O_5, and K_2O are 58.7, 7.7 and 5.8 kg hm^{-2}, respectively); while the whole growth period spraying DPC 3 times.

Experimental field watered with drip irrigation under film mulching with an experimental area of approximately 0.32 hm^2, controlled by a branch tube; three plots of each treatment were used as a branch unit (length is 50 m and width is 1.45 m). The valve and water meters were installed at the unit entrance before the installation of the pressure regulating valve and pressure gauges and the insertion of the drip irrigation tube with thin-walled capillary inserted. The emitters are spaced 30 cm apart. The irrigation system pressure was controlled by a regulating valve, while the irrigation of each treatment was controlled by water meters.

Experimental design

The entire cotton growth period can be divided into seedling stage (stage Ⅰ), bud stage (stage Ⅱ), early flowering and boll stage (stage Ⅲ), late flowering and boll stage (stage Ⅳ) and boll opening stage (stage Ⅴ). Dry seeding wet emergence was adopted; 30 mm (2007) and 45 mm (2009) of irrigation water was applied after sowing. According to the local cotton production practice, both seeding and boll opening stages are not irrigated; therefore, four irrigation treatments were designed in the experiment:

Adequate irrigation treatment (T1): Irrigation was applied when soil water content was approximately 50% of field capacity, receiving irrigation water equality that was 100% of the water surface evaporation at the same stage during the entire cotton growing season. The irrigation lower limit is average water content of 0 to 70 cm soil layer.

The 2nd irrigation level (T2): Irrigation time is as the same as T1, and the irrigation quota is 70% of cumulative water evaporation stage.

The 3rd irrigation level (T3): Irrigation time is as the same as T1, and the irrigation quota is 50% of cumulative water evaporation stage.

The 4th irrigation level (T4): Irrigation time is as the same as T1, and the irrigation quota at budding stages is 70% of cumulative water evaporation stage; the irrigation quota at the late flowering and boll stages is 50% of cumulative water evaporation, and the same irrigation water as T1 during the other stages was applied. Three plots were labeled for replications of each treatment, and each plot was randomly arranged.

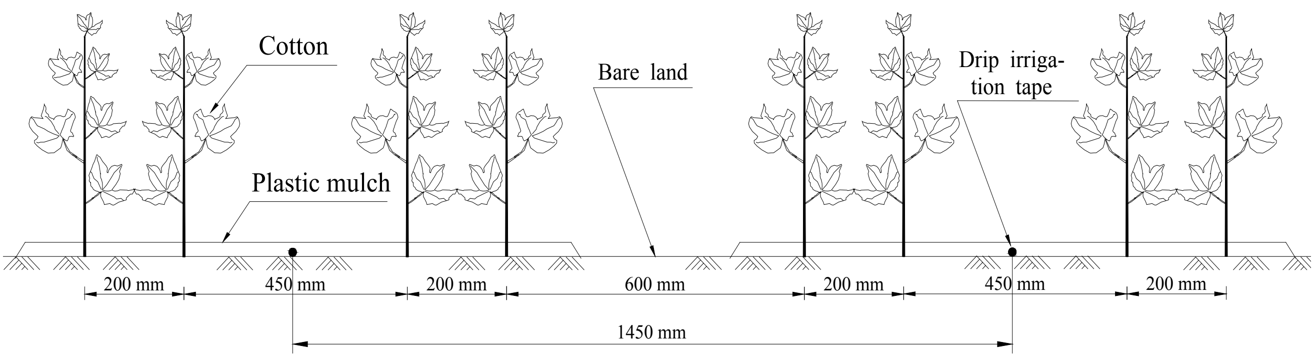

Figure 1: Layout of drip irrigation under mulch with cotton (Unit: mm).

Observation Items and Methods

Soil water measurement:

The soil water contents were taken every 10 cm of the top 0~60 cm depth and 20 cm of the 60~100 cm depth in the planting zone and measured by the oven-drying method. Because field soil moisture of drip irrigation cotton is not a one-dimensional layered distribution and the cultivation characteristics involve the wide and narrow row planting, three sampling points were taken at the wide row (below the drip line under the film mulch), the narrow row (middle of the narrow row under the film mulch) and the bare land outside the mulch. Measurements were taken at an interval of 5~7 days, and extra measurements was taken before and after each irrigation. The average moisture content was calculated according to the reference literature [24].

Morphological index measurement:

Ten tagged plants (five inside and five outside of the row) of every treatment were chosen for the measurement of the morphological index, i.e., plant height, leaf area, the number of bolls, etc. Plant height was measured by steel tapes with an accuracy of 1 mm; length and width of leaves were measured by rulers with an accuracy of 1 mm, and leaf area was determined by multiply of length, width and the coefficient of leaf area. Measurements were taken at an interval of 10 days.

Evaporation of evaporating dish measurement:

Evaporation intensity of free water surface was measured with a simple pan (high 60 cm, diameter 60 cm) made of galvanized iron (0.75 mm of the thick), which was buried in the open space neighboring the experimental field weather station; the open end of the evaporating pan was approximately 20 cm above the ground. A micrometer with an accuracy of 0.02 mm was used to measure the water level of the pan at 8:00 am every day. The water evaporation was calculated by using the difference between the two readings. Replenishment occurred every other day to ensure that there was approximately 5 cm from the water surface to the edge of pan.

Calculation of seed cotton yield and water consumption:

Yield and its components were quantified by measuring the number of bolls, single boll weight, etc. Fifty tagged plants per treatment were randomly chosen at the end of the growing period. For monitoring the actual seed cotton yield of each plot, cotton was harvested twice by hand-picking. All the harvested seed cotton was weighed with electronic weighing scales with an accuracy of 1 g after drying in each plot as the final yield.

Conventional meteorological data:

Meteorological data were gathered at an automatic weather station which was approximately 100 m away from the experimental plots. Meteorological variables measured included air temperature, relative humidity, global radiation, rainfall and wind speed at 2 m above the ground. Changes in reference crop evapotranspiration (ET_0) were calculated with the Penman–Monteith equation.

Experimental Calculation

Crop water consumption according to the water balance equation and water consumption of each treatment was calculated by the formula (1). Because groundwater depths of the experimental plot greater than 15 m, therefore, the effect of groundwater recharge on cotton water consumption was not considered, take K=0. Wang showed that when the dripper flow was 2.8 L·h^{-1} and the irrigation quota was less than 45 mm, deep soil moisture was affected minimally by irrigation [10]. So, there were no deep percolation phenomena; data of soil moisture in the experimental field showed that the irrigation quota is less than 37.5 mm, and irrigation had little effect on soil moisture below the 60 cm soil layer. Therefore, when the irrigation quota is less than 37.5 mm, there is no deep percolation, where D=0. Equation (1) can be simplified to the equation (2).

$$ET=P_0+K+M-D+(W_0-W_t) \tag{1}$$

Where: ET is cotton water consumption (mm); P_0 is effective rainfall (mm); K is the amount of groundwater recharge (mm); M is the amount of irrigation (mm); D is the amount of deep percolation (mm); W_t and W_0, respectively, are for the soil reservoir water of the beginning of the period and the end of the period (mm).

$$ET=P_0+M+(W_0-W_t) \tag{2}$$

Crop water use efficiency: Crop water use efficiency means that crops consumed per unit water to gain production and calculated using the following formulas:

$$WUE=Y/ET_a \tag{3}$$

$$IWUE=Y/I \tag{4}$$

Where: *WUE* and *IWUE,* respectively show water use efficiency and irrigation water use efficiency, kg·m^{-3}; Y is seed cotton yield, kg·hm^{-2}; ET_a is actual water consumption during the entire growth period, m^3·hm^{-2}; I is the amount of irrigation for the entire growth period, as irrigation quota, m^3·hm^{-2}.

Results

Meteorological condition:

Changes in reference crop evapotranspiration (ET_0) in two growing seasons were calculated using the Penman–Monteith equation (Recommended by FAO) in (Figure 2). The results from 2007 showed that ET_0 was relatively small at seeding stages (from May 6 to June 20) with an average of 5.61 mm·d^{-1}; with the advance of the cotton growing process, ET_0 gradually increased and reached its maximum at the budding stage (from June 21 to July 11), with an average value of 7.45 mm·d^{-1}; and then it declines gradually, with an average value of 6.24 mm·d^{-1}, 5.97 mm·d^{-1} and 3.10 mm·d^{-1}, respectively, at the early flowering and boll stage (from July 12 to August 5), late flowering and boll stage (from August 6 to September 1) and boll opening stage (from September 2 to October 20); the average ET_0 was 5.24 mm·d^{-1} during the entire cotton growth period. The results from 2009 showed that ET_0 still remained small at the seedling stage (from May 2 to June 19), with an average number of 5.46 mm·d^{-1}. The ET_0 gradually increased with the advancement of the cotton growing process, and reached its maximum at the budding stage (from June 20 to July 1), with an average of 6.21 mm·d^{-1}; and then it declines gradually, with an average of 5.90 mm·d^{-1}, 5.18 mm·d^{-1} and 2.97 mm·d^{-1}, respectively, during the early flowering and boll stage (from July 13 to August 8), late flowering and boll stage (from August 9 to September 3) and boll opening stage (from September 4 to October 20); the average ET_0 was 4.91 mm·d^{-1} during the entire growth period.

According to the analyzed of surface evaporation, effective rainfall (precipitation was greater than 5 mm) and growth process (Table 1), the alteration process of daily average surface evaporation intensity was approximately the same with ET_0. The data of seeding and boll opening stages were relatively small, but the budding, flowering and boll stages were larger. Precipitation in 2007 and 2009 was approximately 215

Growth stages	Date	Day (d)	Effective rainfall (mm)	Average potential evapotranspiration (mm·d-1)	Evaporation of evaporating pan (mm·d-1)
Seedling	5.6~6.20	46	70	5.61	5.64
Bud stage	6.21~7.11	21	0	7.45	6.06
Early flowering and boll stage	7.12~8.5	25	30	6.24	6.36
Late flowering and boll stage	8.6~9.1	27	45	5.97	5.5
Boll opening	9.2~10.20	49	20	3.1	3.82
Whole stage	5.6~10.20	168	165	5.26	5.24
Seedling	5.2~6.19	49	29	5.46	5.68
Bud stage	6.20~7.12	23	9	6.21	5.61
Early flowering and boll stage	7.13~8.8	27	0	5.9	6.18
Late flowering and boll stage	8.9~9.3	26	8	5.18	4.92
Boll opening	9.4~10.20	47	8	2.97	3.91
Whole stage	5.2~10.20	172	53	4.91	5.15

Table 1: Evapotranspiration and rainfall at each growth stage of cotton with drip irrigation under film mulching.

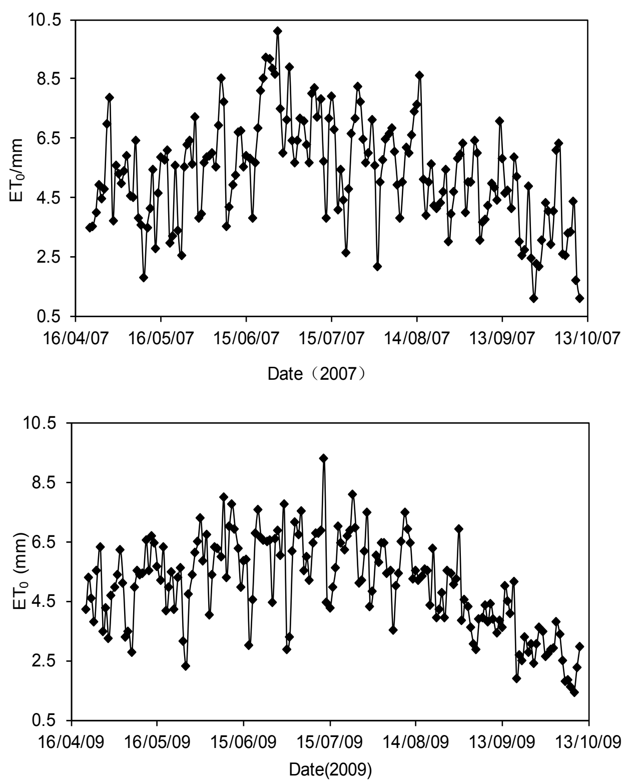

Figure 2: Variation process of ET_0 during the entire cotton growth period.

and 95 mm during the entire growing period, and the effective rainfall (rainfall is more than 5 mm) of the two growing seasons reached 165 and 53 mm, respectively.

Effect of different water treatments on cotton growth:

The cotton plant height is one of the important indexes to measure growth and development of cotton. During different growth stages, especially before topping, the growing rate of plant height is one of the important indexes that reflect the coordination degree between crop vegetative and reproductive growth. An appropriate plant height is suitable for plant type improvement, contributing to a more reasonable distribution of the canopy. The experimental results of two growing seasons (Figure 3) showed that: with drip irrigation under film mulching, as the cotton growing process progressed, plant height gradually increased and the growth rate was faster in both bud and the early flowering and boll stages, and subsequently, the growth rate became very slow. Statistical analysis of the plant height among treatments showed as the following: water treatments are the same during the seeding stages, and the difference of plant height of each treatment was not significantly. However, after entering the bud stages, plant height of T1 was significantly higher than treatment T2 and T3 ($P<0.05$). The plant height of T4 was significantly lower than T1 in the bud stages ($P<0.05$), but at the beginning of the early flowering and boll stage (after seeding 81 days in 2007, after seeding 90 days in 2009), plant height of T4 and T1 is roughly equal; the difference was not significant ($P<0.05$).

Results of leaf area for two growing seasons (Figure 4) showed that: cotton leaf index (*LAI*) increased slowly before bud stages, rapidly growing from the bud stage and reached a maximum peak (after seeding 102 days in 2007, and after seeding 90 days in 2009) at flowering and boll stage, and subsequently, the growth rate gradually decreased. The significant difference analysis showed that: during the seeding stages, the *LAI* of each treatment was not significantly different, but after entering bud stages, *LAI* of T1 was significantly higher than treatment T2 and T3 ($P<0.05$); *LAI* of T4 was significantly lower than T1 in the bud stages ($P<0.05$). At the beginning of the early flowering and boll stage (after seeding 90 days in 2009), *LAI* of treatment T4 and T1 was roughly equal and the difference was not significant ($P<0.05$).

Effect of different treatments on seed cotton yield:

Early summer bolls are mean bolls (diameter larger than 2 cm) that formed before July 15 in the experimental area, while the bolls that formed during July 16 and August 15 are called sweltering summer bolls, where autumn bolls had mean bolls that formed after August 16. Different distributions of bolls in various parts of cotton played diverse roles in the yield due to their formation at different times. The earlier summer bolls formed most favorably in the extension of the effective growing period, and improved the potential of bolls formation per plant [25]. Investigation of early summer bolls revealed that there were more fruit branches, bolls, young bells and early summer bolls for T1, while T3 was the least, but the numbers of bolls of T3 are most. This was due to the continuous small irrigation quota during the bud stage and the flowering and bolls stage and no water compensates in the following stage. Thus, the remaining bolls could not grow and develop normally, and then opened because of the water deficit (in the physical as "drought escape phenomenon"). Sweltering summer bolls are the main component of cotton bolls; their numbers directly determine the seed cotton yield. The results of the investigation showed as the following: the number of sweltering summer bolls for T4 was the highest, followed by T1, while T3 was the lowest. Autumn bolls are outside the space of cotton; their light conditions were best, which have higher boll rate under sufficient water and fertilizer conditions and are also a component of the seed cotton yield. However, Autumn bolls were affected by climate (mainly temperature decline, particularly the end of the frost-free period) at the late growth period, having limits between autumn peach mature and natural boll opening [25]. The investigation found that T1 obtained the most vigorous growth and the highest autumn boll probability, which was due to sufficient water supply, but other treatments were small and showed no significant differences. Results of variance analysis among treatments (Table 2) showed that compared to treatment T1, seed cotton yield of treatments

Year	Treatment	Number of early summer bolls	Number of sweltering summer bolls	Number of autumn bolls	Seed cotton Yield (kg·hm^{-2})
2007	T1	1.40 b	4.80 a	1.30 a	5536.57 a
	T2	1.68 ab	4.20 b	0.75 b	4899.07 b
	T3	2.04 a	2.10 c	0.30 c	2853.30 c
	T4	1.54 b	5.10 a	0.50 bc	5630.19 a
2009	T1	1.18 b	4.08 a	1.06 a	4438.67 a
	T2	1.42 a	3.57 b	0.60 b	3871.04 b
	T3	2.01 b	2.06 c	0.26 b	2895.23 c
	T4	1.23 b	4.34 a	0.39 b	4385.29 a

Table 2: Effects of different water treatments on seed cotton yield.

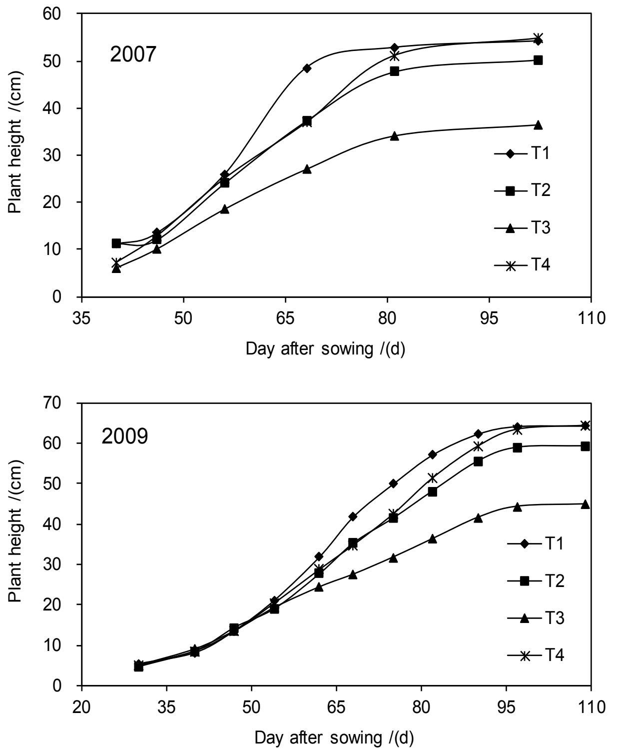

Figure 3: Variation process of plant height under different water treatments.

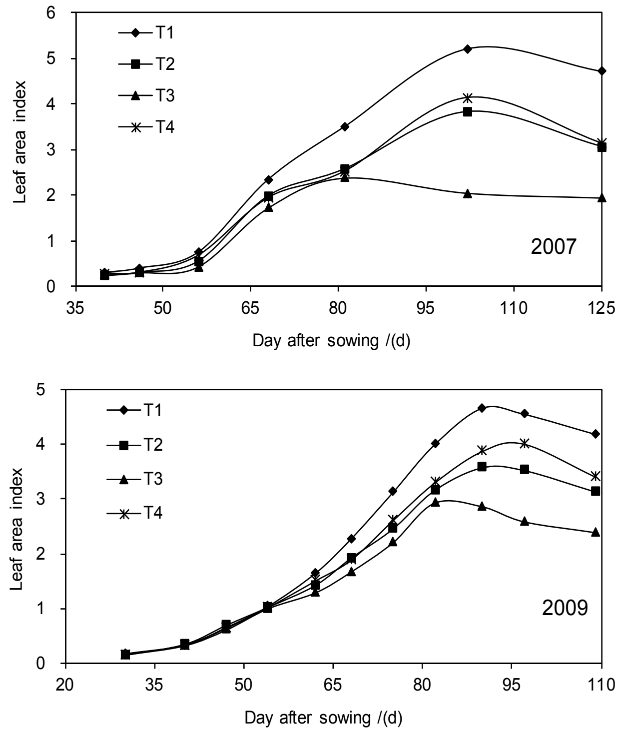

Figure 4: Variation process of leaf area index under different water treatments.

T2 and T3 decreased significantly from 11.51% to 12.79% and from 34.77% to 48.46%, respectively (P<0.05); seed cotton yield of treatment T4 was slightly higher than treatment T1 in year 2007, but slightly lower than treatment T1 in year 2009, and there was no significant difference between two treatments (P<0.05). Comprehensively consideration, treatment T4 was the best irrigation scheme in this experiment.

Effect of different water treatments on cotton water consumption and water use efficiency:

Irrigation of the entire growth period: (Figure 5) showed the irrigation time and irrigation quota for years 2007 and 2009 during the cotton growth period; to ensure emergence, 30 mm irrigation water was applied after sowing. No irrigation was applied during the seedling stage of cotton because of less water consumption and more rainfall (effective rainfall was 70 and 29 mm during 2007 and 2009, respectively). In 2007, irrigation treatments began from the bud stage; the conventional irrigation treatment (T1), the 2nd irrigation level (T2), the 3rd irrigation treatment (T3) and the 4th irrigation level (T4) received the irrigation amount of 420 mm, 303 mm, 225 mm and 315 mm, respectively. Compared to the treatment T1, the treatments T2, T3 and T4 saved irrigation water by 27.85%, 46.43% and 24.88%, respectively. Irrigation treatments in 2009 were as the same as in 2007; T1, T2, T3 and T4 received the irrigation amount of 450 mm, 328.5 mm, 247.5 mm and 347.5 mm, respectively; compared to the treatment T1, the treatments T2, T3, and T4 saved irrigation water by 27.00%, 45.00% and 22.78%, respectively.

Daily average water consumption: The results of water consumption for two growing seasons showed as the following (Figure 6): the seasonal changes in the effect of different water treatments on daily average cotton water consumption were small because of smaller plants and film mulching. Cotton water consumption intensity was small at the seeding stage; access to the nutrition and reproductive

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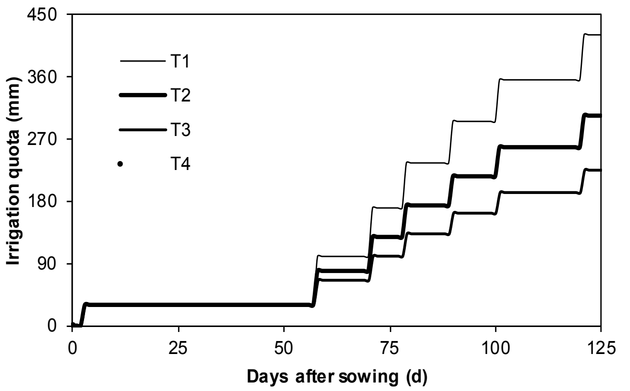

Figure 5: Irrigation treatments of cotton during the whole growth period with drip irrigation under film mulching.

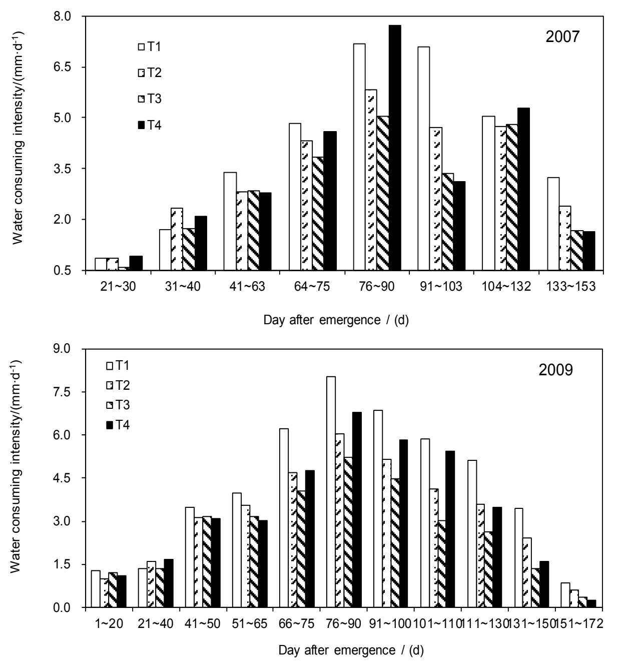

Figure 6: Daily average water consumption of cotton under different water treatments.

growing stages from the bud stage, with the continuous rising temperatures, led to rapidly increasing water consumption. The peak occurred within 75~90 days after sowing. Additionally, daily water consumption decreased gradually with the leaves removed and the temperature decreased from the boll opening stage of cotton. The results from 2007 showed that the water consumption intensity of T2, T3 and T4 appeared to increase within 103~132 days after sowing, due to no irrigation applied from the boll opening stage, and interference caused by the rainfall (the cumulative rainfall exceeded 20 mm). (Figure 5) also showed that water consumption intensity decreased with the decreasing of the irrigation quota.

Effect of different treatments on cotton water use efficiency: Water use efficiency (*WUE*) and irrigation water use efficiency (*IWUE*) of cotton with drip irrigation under film mulching were shown in (Table 3); *WUE* and *IWUE* of Treatment T4 for two growing seasons were the highest, and differences compared to the other treatments were significant ($P<0.05$). The results showed that *WUE* and *IWUE* of treatment T3 for cotton were both the lowest in 2007 and 2009; and the differences compared to the other treatments were significant ($P<0.05$). In (Table 3), *IWUE* of treatment T4 reached 1.78 kg·m^{-3} (2007) and 1.26 kg·m^{-3} (2009), which was 1.35 and 1.28 times to the conventional irrigation treatment (T1). Seed cotton yield and irrigation water use efficiency was promoted under T4 and it was suggested for applying in production practice.

Cumulative water consumption and accumulative evaporation of cotton and evaporation pan coefficient during the entire growth period

The variation process of cumulative evaporation (*ETp*) and cumulative surface evaporation at the same stages during the entire growth stage in 2007 and 2009 were shown in (Figure 7); the cumulative water consumption was much lower than surface evaporation during the early growth stage, but 70 days after sowing, water consumption

	Treatment	Seed cotton Yield (kg·hm^{-2})	Amount of irrigation (mm)	Water consumption (mm)	*WUE* (kg·m^{-3})	*IWUE* (kg·m^{-3})
2007	T1	5536.57 a	420	572.81	0.97 c	1.32 c
	T2	4899.07 b	303	475.3	1.03 b	1.62 b
	T3	2853.30 c	225	414.28	0.69 d	1.27 c
	T4	5630.19 a	315.5	498.34	1.13 a	1.78 a
2009	T1	4438.67 a	450	647.02	0.69 c	0.99 c
	T2	3871.04 b	328.5	500.72	0.77 b	1.18 b
	T3	2895.23 c	247.5	411.92	0.70 b	1.17 b
	T4	4385.29 a	347.5	499.38	0.88 a	1.26 a

Table 3: Water use efficiency and irrigation water use efficiency.

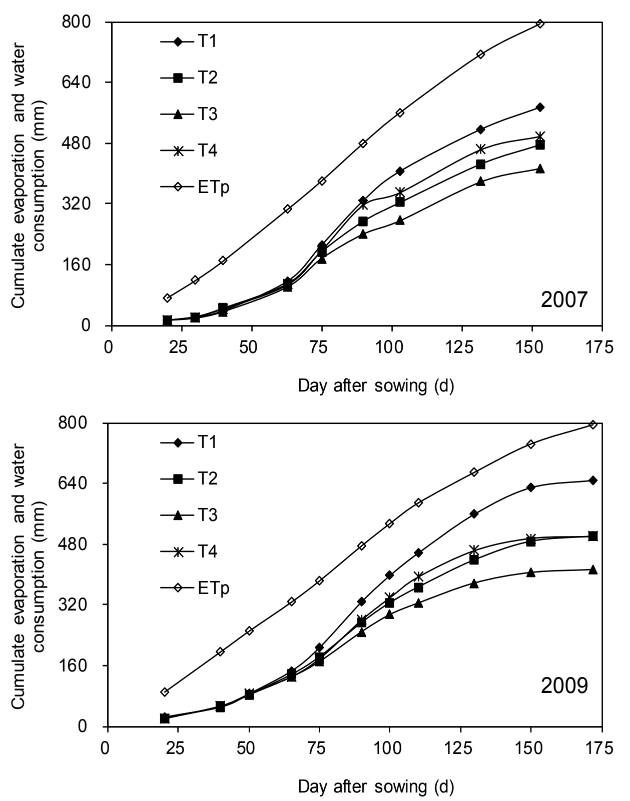

Figure 7: Cumulative water consumption and accumulative evaporation of cotton.

and surface evaporation were approximately the same. The results from 2007 showed as following: cumulative evaporation (*ETp*) was 792.7 mm during the entire growth stage, and cumulative water consumption of cotton during the entire growing periods was 572.81 mm, 475.30 mm, 414.28 mm and 98.34 mm for T1, T2, T3 and T4, respectively. The average pan evaporation coefficient of T1, T2, T3 and T4 was 0.72, 0.60, 0.52 and 0.63, respectively. The results from 2009 showed that cumulative evaporation (*ETp*) was 793.7 mm during the entire growth stage, and cumulative water consumption of cotton during the entire growing period was 647.02 mm, 500.72 mm, 411.92 mm and 499.38 mm for T1, T2, T3 and T4, respectively. The average evaporation pan coefficient of T1, T2, T3 and T4 was 0.82, 0.63, 0.52 and 0.63, respectively. The data analysis also revealed that pan cumulative evaporation has a strong relationship with cotton water consumption, while the correlation coefficient was 0.99 (the number of sample is 11). The evaporation pan coefficient of Treatment T4 in bud stage, the early flowering and boll stage, the late flowering and boll stage was 0.48, 0.87, 0.74 (2007) and 0.52, 0.93, 0.69 (2009) , respectively.

Discussion

As the irrigation system changes, plant height also changes. This article investigated the effect of different irrigation treatments on the plant height of cotton with drip irrigation in Xinjiang. The results indicated that compared to the regular treatment, moderate water stress in bud stage, severe water stress in the late flowering and boll stage and sufficient water in the early flowering and boll stage did not significantly reduce the plant height because of the crop water deficit compensation effect, simultaneity, they were all water saving. Conversely, slightly elevated plant height is conducive to high cotton yield. According to the biological characteristics of cotton and the response of crop growth to the water supply mechanism, timely and appropriate moisture stress can reduce crop luxury transpiration. Generally, slightly decline in photosynthetic rate can regulate the ratio of root to crown and coordinate the relationship between vegetative and reproductive growth. The photosynthetic rate has the effect of compensation or overcompensation after water stress to restore the water supply, which is favorable for photosynthetic products to transport to the reproductive organs, thereby enhancing the seed cotton yield [26-28]. In this article, moderate water deficit during bud stage can control vegetative growth and promote reproductive growth; water stress during the late flowering and boll stage is favorable for boll to naturally boll opening. Cotton growth and the development of seed cotton yield is the most sensitive to moisture stress in the early flowering and boll stage; one episode of water stress will cause irreparable negative effects. Timely and appropriate water deficit cannot lower or reduce economic yield, but significantly improves water use efficiency. In our study, with drip irrigation under film mulching, moderate water stress in bud stage, severe water stress in the late flowering and boll stage and sufficient water in the early flowering and boll stage did not lower the yield, on the contrary, it saved irrigation water resources, significantly improved water use efficiency; which was in accord with previous research results [14,29].

This study also analyzed the impact of different water treatments on the water consumption with drip irrigation under film mulching in Xinjiang. The results implied that the allocation of irrigation quota in the entire growth period was different. The stage water consumption and water consumption in the entire growth period of cotton varied and water consumption of cotton in the entire growth period was 411~647 mm. The results were similar to the study of [30]. The performance of the average daily water consumption intensity for the cotton is early small, middle big, late small. This is because the cotton plant is small during seeding stage, there are fewer leaves, plant transpiration is smaller, average daily water consumption intensity of the cotton fields is lower. At the bud stage, cotton growth began to change from vegetative to reproductive growth, with vigorous growth of cotton plants, leaves and plant transpiration rapidly increased and the average daily water consumption intensity of the cotton fields also significantly increased. The flowering and boll stage is the key period for cotton response to water and fertilizer demand. At reproductive and vegetative growth, response pace is the same where water consumption intensity of the cotton fields at the highest demand, until boll opening stage. However, with lower temperatures and cotton plant aging, water consumption gradually decreases.

Drip irrigation under film mulching had been promoted and applied to a large area in Xinjiang. Since 1998, scholars in China have conducted substantial research on the quality and efficient irrigation system of cotton with drip irrigation, and based on these studies, a variety of high-quality and efficient irrigation indexes have been proposed [3,12]. However, the available indicators applied to the local cotton field moisture management were not very satisfactory, mainly because of the farmers' incomplete irrigation test facilities, and restrictions of the cultural level, which made the physiological and ecological indicators difficult to accurately observe. In addition to these constraints, the soil moisture of cotton fields and environmental indicators that used to determine the irrigation time and irrigation volume was complex. Based on irrigation indicators of water surface evaporation, domestic research mostly concentrated on standard evaporation pan of 20 cm. Study objects were mostly protectorate crops, involving northwest arid zone crops, reporting of drip irrigation under film mulching in Xinjiang is relatively less. In this study, under two growing seasons, it is revealed that: evaporating pan cumulative evaporation has a strong relationship with cotton water consumption; the correlation coefficient was 0.99 (the number of sample is 11). The evaporation pan coefficients of treatment T4 for high yield in bud stage, the early flowering and boll stage, the late flowering and boll stage were 0.48, 0.87, 0.74 (2007) and 0.52, 0.93, 0.69 (2009), respectively. In combination with local climatic conditions and the production practice of cotton, quality and efficient irrigation index can be determined based on simple pan evaporation.

Conclusion

1) Compared to the sufficient water supply treatment of the entire growth period, (T1), water stress significantly inhibits the plant height of the cotton and the growth of the leaf area. However, the plant height and the leaf area index of treatment T4 with moderate water stress in the bud stage, severe water stress in the late flowering and boll stage, sufficient water supply in the early flowering and boll stage, were approximately equal to treatment T1.

2) With the varying irrigation quota, the allocation of irrigation amount in the entire growth period, stage water consumption and water consumption in the entire growth period of cotton were different; with decreasing irrigation quota, the stage water consumption reduced. Compared with treatment T1, water consumption of treatment T4 in the entire growth period decreased by 75~147.64 mm.

3) Compared to treatment T1, the yield of treatments T2 and T3 were reduced by 11.51%~12.79% and 34.77%~48.46%, respectively, and the differences were significant ($P < 0.05$). Seed cotton yield of treatment T4 was slightly higher than treatment T1 in 2007; seed cotton yield of treatment T4 was slightly lower than treatment T1 in 2009, hence the yield differences in treatments T1 and T4 for

the two growing seasons were not significant (P <0.05). Therefore, comprehensively considering the experimental data from two growing seasons, with the desired yield, treatment T4 saved 22.78%~24.88% of irrigation water resources and irrigation water use efficiency was improved by 27.94%~34.85%.

4) The relationship between the cumulative water consumption of high yield fields (T4) and accumulation of 60 cm evaporation pan indicated that: stage cumulative water consumption of high yield fields has a good relationship with accumulation surface evaporation for the same period, and the value of R^2 is more than 0.99. The *Kp* of the bud stage, the early flowering and boll stage, the late flowering and boll stage for high yield cotton fields with drip irrigation under film mulching were 0.48~0.52, 0.87~0.93 and 0.69~0.74, respectively, which can be beneficial for the evaporation pan evaporation to guide cotton field moisture management. Combining local climatic conditions with the production practice of cotton, quality and efficient irrigation index can be determined based on simple pan evaporation: with dry seeding and irrigation with 30~45 mm emergence water, there is no irrigation in the seedling stage. Irrigation quota is determined in the bud stage, the early flowering and boll stage, the late flowering and boll stage, according to the multiplication between pan cumulative evaporation and K_p (values of the bud stage, the early flowering and boll stage, the late flowering and boll stage are, respectively, taken 0.5, 0.9, 0.7). The irrigation cycle is taken 9~12 days in the bud stage, 5~7 d in the early flowering and boll stage, 7~10 d in the late flowering and boll stage; there is no irrigation in the boll opening stage.

Acknowledgement

We are grateful to the support by the National High-Tech 863 Project of China (2011AA100502), the National High-Tech 863 Project of China (2011AA100509). And we also would like to thank the staffs of the Key Laboratory of Crop Water Use and Regulation, Ministry of Agriculture, P. R. China.

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Citation: Xiaojun S, Mingsi L, Jiyang Z, Zugui L, Guisen Y, et al. (2016) Study on Optimal Irrigation Index of Cotton with Drip Irrigation under Film Mulching based on Pan Evaporation. Irrigat Drainage Sys Eng 5: 160. doi:10.4172/2168-9768.1000160