APPROPRIATE SUBSURFACE DRIP IRRIGATION DEPTH CAN IMPROVE THE PHOTOSYNTHETIC CAPACITY AND INCREASE THE ECONOMIC COEFFICIENT OF COTTON WITHOUT PLASTIC MULCHING

DUAN, J.[1#] – WANG, G.[2#] – WANG, J.[2] – HAO, X.[2] – LUO, H.[1*] – YANG, G.[3*]

[1]*College of Agronomy, Shihezi University, Shihezi, Xinjiang 832000, China*

[2]*Xinjiang Academy of Agricultural Reclamation Sciences, Shihezi, Xinjiang 832000, China*

[3]*College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei 430070, China*

[#]*These authors contributed equally to this work.*

[*]*Corresponding authors*
e-mail: luohonghai@shzu.edu.cn, ygzh9999@mail.hzau.edu.cn
phone: +86-133-4546-6760; +86-139-9555-3884

(Received 7th Mar 2022 ; accepted 20th Jun 2022)

Abstract. Residual film pollution in fields is the main problem affecting the sustainable development of agriculture. Cultivation without plastic mulching is the best way to reduce the accumulation of residual film. Therefore, we investigated the effects of three depths of embedded drip irrigation belts (10 cm, 15 cm and 20 cm) on the photosynthetic traits and yield of cotton without plastic mulching. From Biologische Bundesanstalt, Bundessortenamt and Chemical industry (BBCH) 65 to 75, the cotton leaf area of the 10 cm and 15 cm treatments decreased by 45.0% and 25.4%, respectively, while the cotton leaf area of the 20 cm treatment increased by 8.3%. With increasing depth, the SPAD value, net photosynthetic rate, intercellular CO_2 concentration, transpiration rate, stomatal conductance, quantum efficiency of PSII, electron transport rate, photochemical quenching coefficient and maximal quantum yield of PSII photochemistry increased. Compared with the 10 cm and 15 cm treatments, the biological yield of the 20 cm treatment was 51% and 33% higher, and the seed cotton yield was 15% and 2% highter, but the economic coefficient was 24%, lower. Hence, 15 cm is the optimum depth to enhance the photosynthetic capacity and ensure the maximum economic coefficient of cotton without plastic mulching.
Keywords: *diffused pollution, growth, photosynthesis, localized irrigation, yield*

Introduction

Cotton is an important fiber and oil crop worldwide (Constable and Bange, 2015). China is one of the world's major cotton producers (Wang et al., 2020). Film mulching technology has made an important contribution to the development of the cotton industry in Xinjiang, the most important high-quality cotton production base in China (Li et al., 2004; He et al., 2018). However, the promotion and use of plastic mulching have not only brought huge economic benefits but have also contributed to residual film pollution in cotton fields, seriously affecting seedling emergence and the development of the root system of cotton, and thus reducing cotton yield. Therefore, preventing and/or controlling residual film pollution is a matter of great urgency (Zhang et al., 2016; Gao et al., 2019). Compared with degradable plastic film mulching and plastic film recovery, cultivation without plastic mulching is the most direct and effective way to reduce the accumulation of residual film.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

Due to the loss of the beneficial effects of mulching film, including increasing the temperature and preserving moisture, cotton in fields without plastic mulching is faced with problems such as a delayed sowing date, evaporation of soil water and yield reduction. Based on previous studies, we assumed that the above problems can be solved by using early-maturing cotton cultivars, reasonable chemical regulation and increasing sowing density under subsurface drip irrigation (Dong et al., 2005; Chen et al., 2018). Subsurface drip irrigation technology can effectively control the retention of irrigation water in the root zone of crops via drip irrigation belts embedded in the soil (Ayars et al., 2015). Compared with traditional surface drip irrigation, subsurface drip irrigation can significantly improve the water use efficiency and yield of cotton in drought regions (Kalfountzos et al., 2006; Çetin et al., 2021).

Improving photosynthetic performance is of great significance for improving cotton production potential. The key to improving the photosynthetic capacity of cotton without plastic mulching is to optimize the spatial distribution of soil water. The main factors affecting soil water movement include the soil texture, depth of the embedded drip irrigation belt, irrigation amount and drip hole flow under subsurface drip irrigation (Amali et al., 1997). In recent years, many researchers have carried out studies on the characteristics of soil water and salt transport, the arrangement of drip irrigation belts, irrigation quotas and irrigation frequency under subsurface drip irrigation and have proposed reasonable irrigation systems and cultural practices (Grabow et al., 2006; Elmaloglou and Diamantopoulos, 2013; Yao et al., 2021). Since subsurface drip irrigation achieves water conservation through the soil layer above the drip irrigation belt and the depth of the embedded drip irrigation belt has a significant effect on soil water transport and crop water absorption and utilization (Guo et al., 2020), it is important to explore the influence of the embedded belt depth on crop growth and the underlying mechanisms. Khalilian et al. (2000) noted that the embedded depth of a drip irrigation belt had an effect on cotton yield. Chen (2017) found that when the drip irrigation belt is embedded in an appropriate position, it can not only meet the normal water demand of crops but can also significantly reduce soil evaporation and inhibit the growth of weeds.

However, there are few studies on the effects of different depths of embedded drip irrigation belts on the photosynthetic characteristics and yield of cotton without plastic mulching. Therefore, the purpose of the study was to determine the responses of the relative water content of cotton leaves, leaf area, leaf mass per area, SPAD value, chlorophyll fluorescence parameters, gas exchange parameters and yield to three different embedded belt depth treatments using a Xinjiang self-bred early-maturing cotton cultivar, Xinluzao 74 (*Gossypium hirsutum* L.), and adopting the same row spacing cultivation mode of 76 cm without plastic mulching. This study also included correlation analysis of photosynthetic characteristics and yield to provide a theoretical basis and technical support for high-efficiency production of cotton without plastic mulching in Xinjiang.

Materials and methods

Experimental site and cultivar

The experiments were conducted at the Shihezi Experimental Observation Station of Crop Water Efficiency, Ministry of Agriculture/Soil and Water Institute of Xinjiang Academy of Agricultural Reclamation Sciences, Shihezi, Xinjiang, China (86°09’ E, 45°38’ N) from April to October 2019. The average altitude of this area is 430 m. The texture of the soil at the experimental site is loam, and the soil had the following initial

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

characteristics: 7.86 pH, 23 g kg^{-1} organic matter, 29 mg kg^{-1} available phosphorus, and 174 mg kg^{-1} available potassium in the 0−20 cm layer. The average bulk density from 0−100 cm was 1.40 g cm^{-3}, the field capacity was 24.0%, and the groundwater depth was less than 10 m. During the growing period, the total precipitation was 98.2 mm, with 7 events with an effective precipitation greater than 5 mm. From May 1 to August 31, the daily mean maximum temperature was 30.9°C, and the daily mean minimum temperature was 16.2°C. The daily mean temperature from April to October was 18.7°C. The meteorological indexes during the growing period of 2019 at the experimental site were all at the average levels for the past decade. Xinluzao 74 (*Gossypium hirsutum* L.), an early-maturing cotton cultivar, was used in the experiment and was provided by the Cotton Research Institute of Shihezi Academy of Agricultural Sciences (the growth period is 120 days, the prefrost flowering rate is highter than 95%, and the cultivar's strong growth potential and stress resistance are suitable to allow machine picking).

Experimental design and management

The experiments were conducted in a randomized block design with three different embedded belt depth treatments (Li et al., 2017): D_1 (10 cm), D_2 (15 cm), and D_3 (20 cm). The plot size was 45.6 m^2 (10 m × 4.56 m), with three replications. An anti-siphon dripline (*DripNet*, *Netafim*, Israel) was adopted, with an emission rate of 1.0 L h^{-1}, and the drop head spacing was 30 cm. Drip irrigation belts were laid with a spacing of 1.52 m with one drip irrigation belt covering two rows. The total irrigation amount was 262.5 mm (Liu, 2006) (*Table 1*).

Table 1. *Irrigation cycles and irrigation amount*

Date	Irrigation amount [mm]		
	D_1	D_2	D_3
06-15	18.0	18.0	18.0
06-22	18.0	18.0	18.0
06-29	18.0	18.0	18.0
07-01	21.0	21.0	21.0
07-03	21.0	21.0	21.0
07-05	21.0	21.0	21.0
07-09	24.0	24.0	24.0
07-15	24.0	24.0	24.0
07-21	27.0	27.0	27.0
07-27	27.0	27.0	27.0
08-07	21.0	21.0	21.0
08-20	15.0	15.0	15.0
08-30	7.5	7.5	7.5
Total	262.5	262.5	262.5

Seeds were sown 38 cm from the horizontal drip irrigation belt on 3 May 2019, 2.0–3.0 cm deep and with a 76 cm equal row spacing. Pendimethalin (2700~3000ml ha^{-1}) was sprayed evenly on the soil on 26 April for weed control. After sowing, irrigation was carried out twice, with 15.0 mm each time. Seedlings were thinned to 5 cm after cotyledon flattening to maintain a planting density of 265,000 plants ha^{-1}. The basal fertilizers were urea (N 46%, mass fraction, the same below) applied at 150 kg ha^{-1} and phosphate fertilizer (P_2O_5 45%) applied at 225 kg ha^{-1}. Urea (N 46%; 525 kg ha^{-1}; the ratio for the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

seedling, budding, flowering and boll-setting stages was 1:4:5) and potassium dihydrogen phosphate (P_2O_5 52%, K_2O 34%; 150 kg ha^{-1}; the ratio at the budding, flowering and boll-setting stages was 4:6) were applied with water throughout the whole growth period. Disease and insect control was carried out three times, in the full bud stage (late June), in the full flowering stage (mid-July) and in the full boll stage (late July). The initial application consisted of acetamiprid (0.22 kg ha^{-1}) and abamectin etoxazole (0.32 kg ha^{-1}). The second application consisted of acetamiprid (0.27 kg ha^{-1}) and abamectin etoxazole (0.18 kg ha^{-1}). The third application consisted of nitenpyram pymetrozine (0.46 kg ha^{-1}), acetamiprid (0.46 kg ha^{-1}), abamectin (0.23 kg ha^{-1}) and emamectin benzoate (0.46 kg ha^{-1}). A defoliation/ripening agent (thidiazuron, 195 ml ha^{-1}; ethephon, 1380 ml ha^{-1}) was sprayed on 22 September. The second application (ethephon, 870 ml ha^{-1}) was carried out on 8 October. Other field management practices were conducted according to local practices (*Figure 1*).

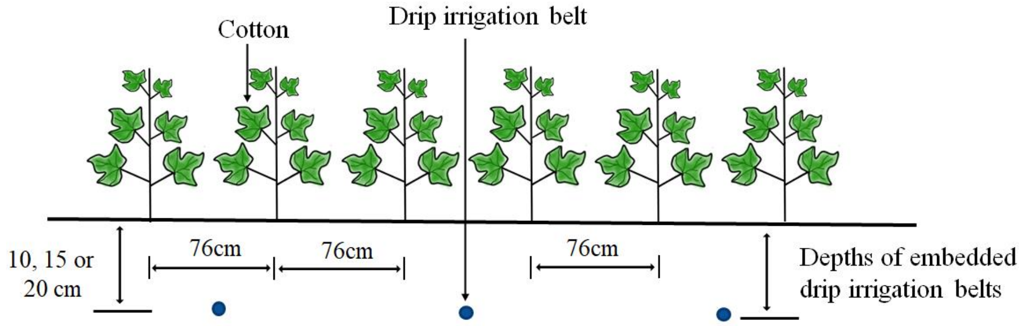

Figure 1. *Schematic diagram of the planting mode at the experimental site*

Leaf area

The proportion method was used to measure the whole leaf area of cotton (Shi, 2012). In Biologische Bundesanstalt, Bundessortenamt and Chemical industry (BBCH) stages 52 (1st floral bud detectable ('match-head square')), 61 (beginning of flowering ('early bloom'): 5-6 blooms/7.5 meter of row), 65 (main phase of flowering ('mid bloom'): 11 or more blooms/7.5 meter of row) and 75 (approximately 50% of bolls have attained their final size) (Munger, 1998), a 6-mm-hole punch was used to remove 40 small round pieces from all leaves of each plant, and these pieces were put into craft paper bags and weighed after oven drying at 105°C for 30 min followed by drying at 80°C to a constant weight. The leaf area of a whole plant was determined as follows:

$$\text{Leaf area of a whole plant} = \frac{\text{dry leaf weight of the whole plant} \times \text{circular leaf area}}{\text{circular dry weight}} \quad \text{(Eq.1)}$$

Leaf relative water content

The relative water content of the functional leaves of the cotton main stem (fourth or third leaf from the top) was measured at BBCH 52, 61, 65 and 85 (approximately 50% of bolls open). Five round pieces were collected using a hole punch to avoid leaf veins, and the fresh weight (FW) was determined by weighing; the process was repeated 4 times. The round pieces were immersed in distilled water for 24 h to saturate the tissue with water. The material was removed from the distilled water, absorbent paper was used to

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

absorb the surface moisture, and the saturated fresh weight (SFW) was determined by weighing. Then the samples were placed in water for 1 h, and the SFW was determined again. The materials were dried in an oven at 105°C for 30 min followed by drying at 80°C to a constant weight for dry weight (DW) determination. The relative water content (RWC) was calculated as follows:

$$\mathrm{RWC} = \frac{\mathrm{FW{-}DW}}{\mathrm{SFW{-}DW}} \times 100\% \qquad \text{(Eq.2)}$$

Leaf mass per area

At BBCH 52, 61, 65, 75 and 79 (approximately 90% of bolls attained their final size), a 6 mm hole punch was used to remove 5 small round pieces from the functional leaves of the cotton (fourth or third leaf from the top), and these pieces were put into craft paper bags and dried in an oven at 105°C for 30 min followed by drying at 80°C to a constant weight and were then weighed. The specific leaf weight was calculated as follows:

$$\text{Leaf mass per area} = \frac{\text{circular dry weight}}{\text{circular leaf area}} \qquad \text{(Eq.3)}$$

Leaf SPAD value

Four plants with uniform growth from each treatment group were selected at BBCH 52, 61, 65, 75 and 79. The chlorophyll (SPAD) concentrations of the main stem functional leaves were measured by a SPAD instrument (*SPAD-502Plus*, *KONICA MINOLTA*, Chiyoda-ku, Tokyo, Japan) from 10:00 to 11:00 on the same day, and the average value of five points measured per leaf was calculated.

Leaf gas exchange

The net photosynthetic rate (P_N), stomatal conductance (g_s), intercellular CO_2 concentration (C_i) and transpiration rate (E) of the functional leaves (fourth or third leaf from the top) of cotton with good growth were measured at BBCH 52, 61, 65, 75 and 79 by using an open-type photosynthetic measurement system (*LI-6800*, *LI-COR*, Lincoln, NE, USA) with steady light intensity (1800 µmol m^{-2} s^{-1}), and the temperature was controlled to 32°C. The ambient CO_2 concentration was basically stable at 400 µmol mol^{-1}, and the relative humidity was 30~32%. Each treatment was measured 4 times.

Chlorophyll fluorescence parameters

The chlorophyll fluorescence parameters of the functional leaves of the main stem were measured at BBCH 52, 61, 65, 75 and 79 using a pulse-amplitude modulation portable fluorometer (*Mini-PAM*, *Heinz Walz GmbH*, Effeltrich, Germany). The measurement indexes included the maximal quantum yield of PSII photochemistry (F_v/F_m), quantum efficiency of PSII (Y_{II}), electron transport rate (ETR), photochemical quenching coefficient (q_P) and nonphotochemical quenching coefficient (NPQ).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

Economic coefficient

The middle section of each plot was designated (2×1.52) m^2 as the test production area at BBCH 85 (130 days after seedling emergence), and the yield was calculated according to the actual harvest yield. At the same time, four plants with uniform growth were selected in each treatment group. Samples were taken from 6 tissues, i.e., leaves, stems, roots, buds, flowers and bolls, put into craft paper bags, and dried in an oven at 105°C for 30 min followed by drying at 80°C to a constant weight. The dry weight was measured to calculate the biological yield. The economic coefficient was calculated as follows:

$$\text{Economic coefficient} = \frac{\text{seed cotton yield}}{\text{biological yield}} \quad \text{(Eq.4)}$$

Statistical analysis

The experiment was laid out in a randomized block design with three different embedded belt depth treatments: D_1 (10 cm), D_2 (15 cm) and D_3 (20 cm). The plot size was 10 × 4.56 m^2 with three replications. *Microsoft Excel 2010* and *SigmaPlot 14.0* (*Systat Software Inc*., San Jose, CA, USA) were employed for data processing and drawing the figures, respectively. *SPSS 23* (*SPSS Inc*., Chicago, IL, USA) was used for one-way analysis of variance (ANOVA). The significance of differences between the treatment means was determined using Duncan's test at the $P < 0.05$ level in the same period.

Results

Leaf area and leaf mass per area

The experimental results (*Figure 2*) showed that from BBCH 52 to 75, the cotton leaf area in the D_1 and D_2 treatments first increased and then decreased. From BBCH 65 to 75, the cotton leaf area in the D_1 and D_2 treatments decreased by 45.0% and 25.4%, respectively, while that in the D_3 treatment increased by 8.3%.

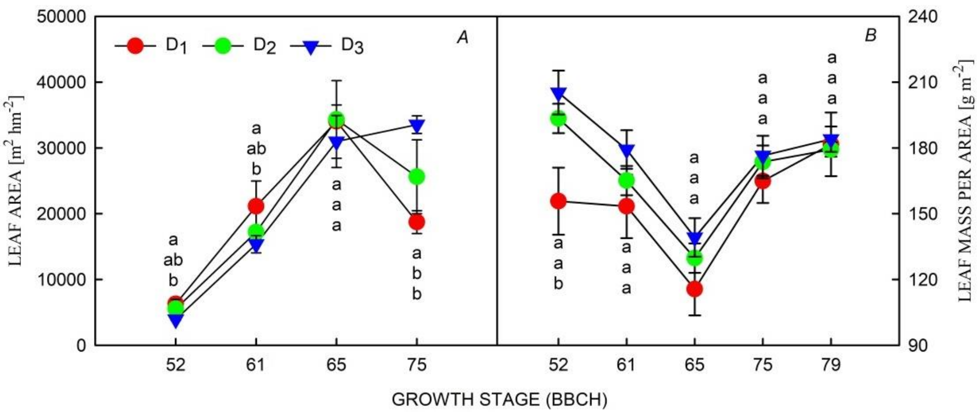

Figure 2. *Effect of the embedded drip irrigation belt depth on the leaf area and leaf mass per area of cotton at BBCH 52, 61, 65, 75 and 79. The treatments D_1, D_2 and D_3 represent embedded belt depths of 10, 15 and 20 cm, respectively. Error bars show the standard error (SE) of the means. Different lowercase letters in the figure indicate statistical significance at the P = 0.05 level within the same stage. Leaf SPAD values and relative water contents*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

The depth of the embedded drip irrigation belt had an effect only on the leaf mass per area at BBCH 52, with values 24.2% and 31.8% higher in the respective D_2 and D_3 treatments than in the D_1 treatment.

The study showed that the depth of the embedded drip irrigation belt had a significant impact on the SPAD at BBCH 52, 61 and 79 (*Figure 3*). The greater embedded belt depth under D_3 resulted in a significantly higher SPAD value than that under D_1, and D_2 was significantly different from D_3 only at BBCH 61.

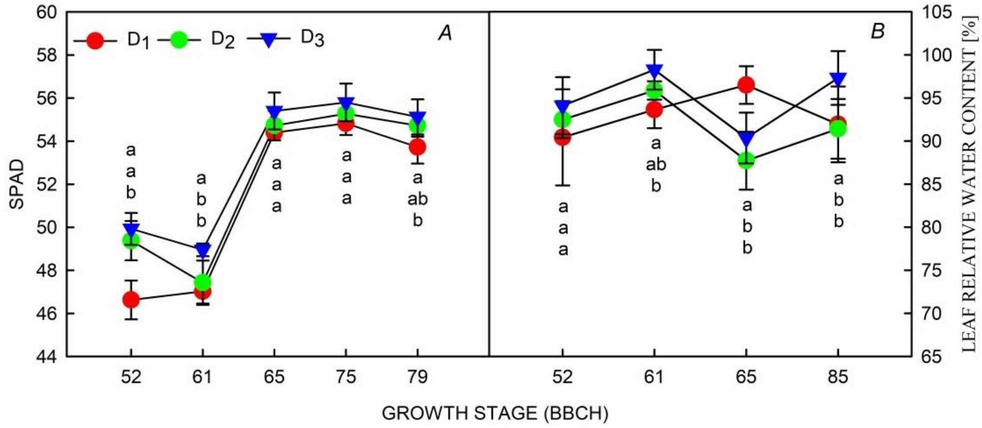

Figure 3. *Effect of embedded drip irrigation belt depth on the SPAD value and relative water content of cotton at BBCH 52, 61, 65, 75 and 79. The treatments D_1, D_2 and D_3 represent embedded belt depths of 10, 15 and 20 cm, respectively. Error bars show the standard error (SE) of the means. Different lowercase letters in the figure indicate statistical significance at the P = 0.05 level within the same stage*

There was no significant difference in leaf RWC among all treatments at BBCH 52. From BBCH 61 to 65, the relative water content of cotton leaves in D_2 and D_3 decreased by 8.5% and 8.1%, respectively, while that in D_1 increased by 3%. From BBCH 65 to 85, the relative water content of cotton leaves in D_2 and D_3 increased by 4.2% and 7.7%, respectively, while that in D_1 decreased by 4.7%.

Gas exchange parameters

The net photosynthetic rate (P_N), intercellular CO_2 concentration (C_i) and transpiration rate (E) of functional cotton leaves increased as the embedment depth increased after BBCH 61 (*Figure 4*). There was no significant difference among all treatments at BBCH 61. Stomatal conductance (g_s) increased with increasing depth of the embedded drip irrigation belt, and the g_s in D_3 was significantly different from that in D_2 only at BBCH 61; there was no significant difference in the other stages.

Chlorophyll fluorescence parameters

The results (*Figure 5*) showed that the depth of the embedded drip irrigation belt had a significant effect only on the maximal quantum yield of PSII photochemistry (F_v/F_m) at BBCH 79, and the values under the D_3 treatments were 1.8% higher than those under D_1. The quantum efficiency of PSII (Y_{II}), the electron transport rate (ETR) and the photochemical quenching coefficient (q_P) increased with increasing belt depth, and D_3 resulted in significantly higher values than D_1. The depth of the belt had a significant

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

effect only on the nonphotochemical quenching coefficient (NPQ) of cotton leaves at BBCH 61, with 10.4% and 18.0% lower values in D_2 and D_3, respectively, compared with those in D_1.

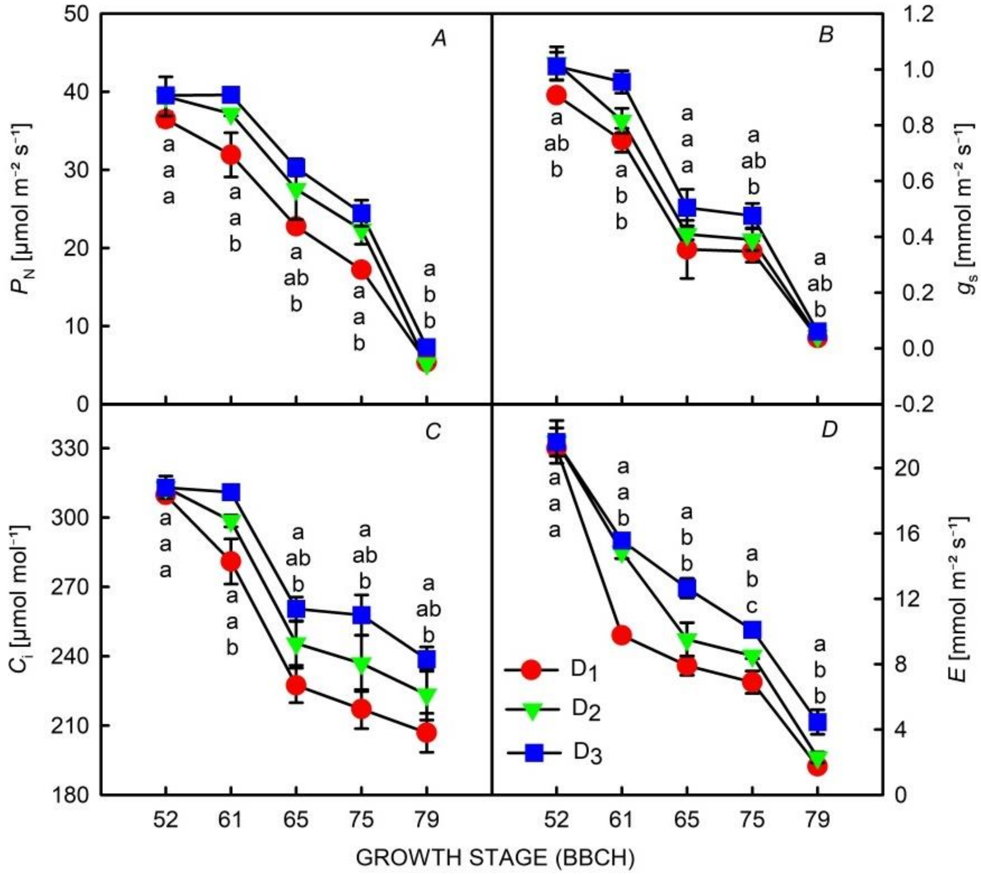

***Figure 4.** Effect of the embedded drip irrigation belt depth on cotton gas exchange parameters at BBCH 52, 61, 65, 75 and 79. The treatments D_1, D_2 and D_3 represent embedded belt depths of 10, 15 and 20 cm, respectively. P_N, g_s, C_i and E represent the net photosynthetic rate, stomatal conductance, intercellular CO_2 concentration and transpiration rate, respectively. Error bars show the standard error (SE) of the means. Different lowercase letters in the figure indicate statistical significance at the P = 0.05 level within the same stage.*

Biological yield, seed cotton yield and economic coefficient

The experiment showed that compared with D_1 and D_2, the biological yield of D_3 increased by 51% and 33%, and the seed cotton yield increased by 15% and 2%, but the economic coefficient decreased by 24% and 24%, respectively (*Figure 6*). There was no significant difference in seed cotton yield between D_3 and D_2.

Correlation analysis between photosynthetic parameters and cotton yield

Seed cotton yield was positively correlated with g_s at BBCH 52 and 61, Y_{II} and ETR at BBCH 65 and 79, q_P at BBCH 61 and 65, P_N and E at BBCH 61 and 75, and C_i at BBCH 61 to 75. Seed cotton yield was negatively correlated with NPQ at BBCH 61 and 65 (Table 2). Biological yield was positively correlated with F_v/F_m at BBCH 79, Y_{II} at BBCH 52 and 79, ETR and q_P at BBCH 52 to 79, P_N at BBCH 61, 75 and 79, E and C_i at

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

BBCH 61 to 79, and g_s at BBCH 61. There was a significant negative correlation between biological yield and NPQ at BBCH 61. The economic coefficient was negatively correlated with F_v/F_m at BBCH 65, Y_{II} at BBCH 79, ETR and q_P at BBCH 52, 75 and 79, P_N at BBCH 61, g_s at BBCH 61 and 79, C_i at BBCH 75 and 79, and E at BBCH 65 and 79. There was a significant positive correlation between the cotton economic coefficient and NPQ at BBCH 61 (*Table 2*).

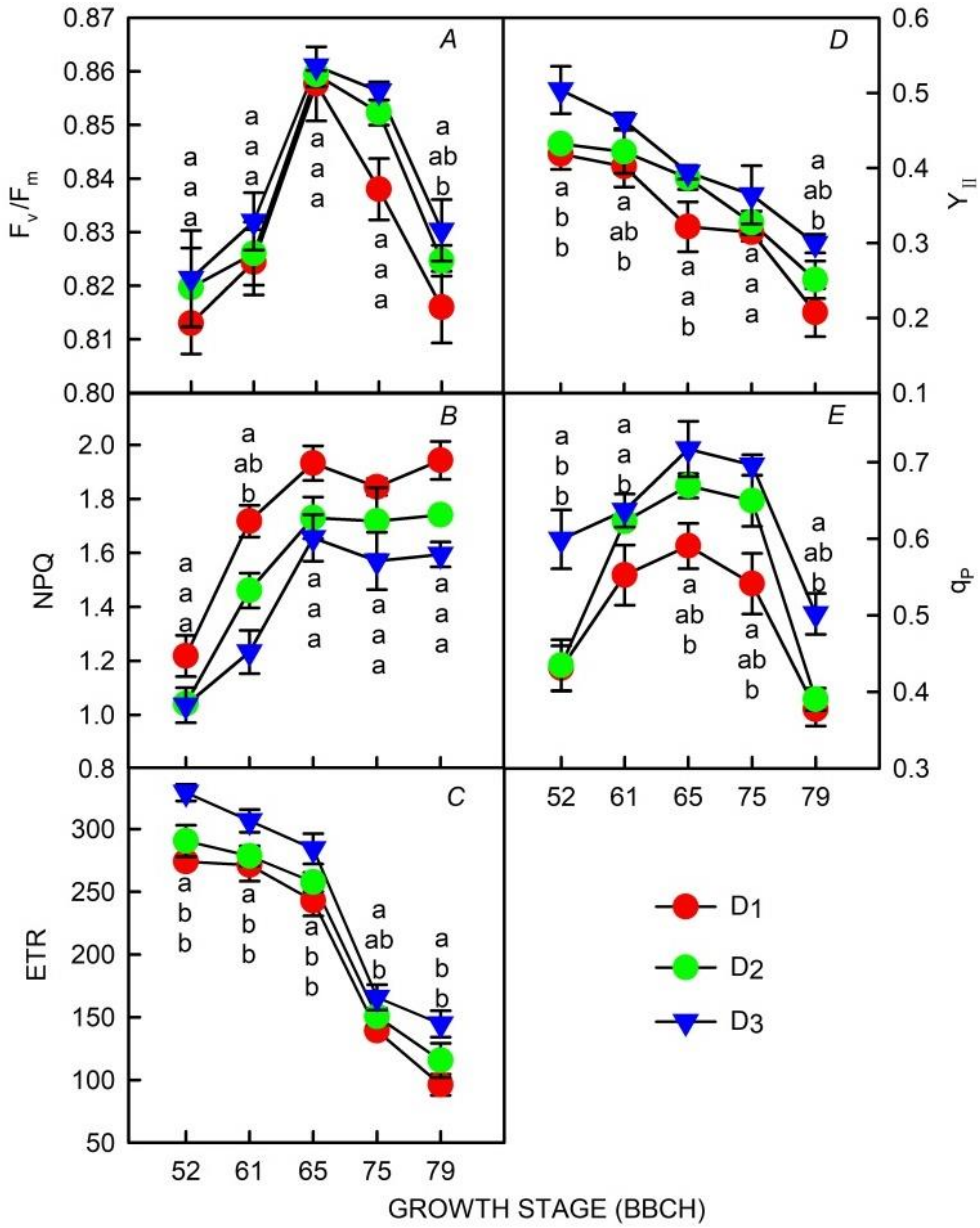

Figure 5. *Effect of embedded drip irrigation belt depth on the cotton chlorophyll fluorescence parameters at BBCH 52, 61, 65, 75 and 79. The treatments D_1, D_2 and D_3 represent embedded belt depths of 10, 15 and 20 cm, respectively. F_v/F_m, NPQ, ETR, Y_{II} and q_P represent the maximal quantum yield of PSII photochemistry, the nonphotochemical quenching coefficient, the electron transport rate, the quantum efficiency of PSII and the photochemical quenching coefficient, respectively. Error bars show the standard error (SE) of the means. Different lowercase letters in the figure indicate statistical significance at the P = 0.05 level within the same stage*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

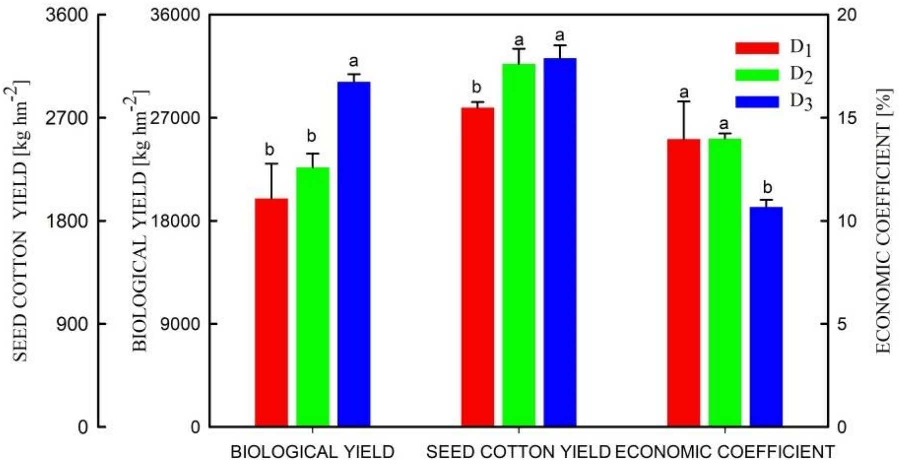

Figure 6. *Effect of embedded drip irrigation belt depth on the biological yield, seed cotton yield and economic coefficient of cotton. The treatments D_1, D_2 and D_3 represent embedded belt depths of 10, 15 and 20 cm, respectively. Error bars show the standard error (SE) of the means. Different lowercase letters in the figure indicate statistical significance at the P = 0.05 level within the same stage*

Table 2. *Correlation analysis between photosynthetic parameters and yield of cotton at different growth stages*

Growth stage (BBCH)	Parameter	F_v/F_m	Y_{II}	NPQ	ETR	q_P	P_N [μmol m^{-2} s^{-1}]	C_i [μmol mol^{-1}]	g_s [mmol m^{-2} s^{-1}]	E [mmol m^{-2} s^{-1}]
52	Seed cotton yield	0.371	0.653	-0.341	0.589	0.558	0.453	0.399	0.810 **	0.327
	Biological yield	0.270	0.738 *	-0.051	0.857 **	0.873 **	0.487	0.166	0.476	0.133
	Economic coefficient	-0.138	-0.537	-0.147	-0.831 **	-0.837 **	-0.482	0.030	-0.291	-0.054
61	Seed cotton yield	0.311	0.460	-0.697*	0.656	0.740*	0.825**	0.724*	0.712*	0.953**
	Biological yield	0.386	0.604	-0.808**	0.779*	0.678*	0.847**	0.759*	0.854**	0.741*
	Economic coefficient	-0.289	-0.538	0.712*	-0.610	-0.569	-0.772*	-0.628	-0.776*	-0.546
65	Seed cotton yield	0.317	0.791*	-0.720*	0.760*	0.712*	0.573	0.690*	0.490	0.632
	Biological yield	0.551	0.659	-0.663	0.773*	0.722*	0.621	0.754*	0.462	0.802**
	Economic coefficient	-0.677*	-0.515	0.547	-0.587	-0.633	-0.504	-0.617	-0.230	-0.676*
75	Seed cotton yield	0.540	0.476	-0.291	0.641	0.602	0.803**	0.729*	0.595	0.798**
	Biological yield	0.270	0.600	-0.532	0.786*	0.692*	0.711*	0.839**	0.625	0.764*
	Economic coefficient	0.005	-0.448	0.598	-0.736*	-0.681*	-0.576	-0.755*	-0.444	-0.555
79	Seed cotton yield	0.628	0.720*	-0.392	0.747*	0.380	0.422	0.658	0.331	0.606
	Biological yield	0.679*	0.912**	-0.546	0.834**	0.781*	0.731*	0.807**	0.666	0.865**
	Economic coefficient	-0.589	-0.884**	0.592	-0.684*	-0.826**	-0.620	-0.756*	-0.709*	-0.813**

* Significant correlation at the 0.05 level (bilateral). ** Significant correlation at the 0.01 level (bilateral).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

Discussion

Regulation of cotton photosynthetic characteristics by embedded drip irrigation belt depth

The depth of irrigation and fertilization can affect the photosynthesis of the aboveground parts of crops and thus affect yield formation in fields without plastic mulching (He, 2001). The leaf is the main organ for photosynthesis. Maintaining appropriate leaf area dynamics at each growth stage of crops is critical for improving yield (Maddonni et al., 2001). The results of this experiment showed that compared with BBCH 65, the leaf area at BBCH 75 decreased by 45.0% and 25.4% in D_1 and D_2, respectively, and increased by 8.3% in D_3, indicating that an increase in the depth of the embedded drip irrigation belt led to an increase in leaf area after BBCH 65 and prevented premature senescence. Combined with the fact that the relative water content in D_2 and D_3 was significantly lower than that in D_1 at BBCH 65 in this experiment, this indicates that the water consumption of cotton plants in the D_2 and D_3 treatments was relatively high during this stage, and D_2 and D_3 maintained stronger growth potential in the later growth stage than D_1. In addition, in this experiment, the relative water content of cotton leaves at BBCH 52, 61 and 85 and the SPAD value at BBCH 52, 61 and 79 significantly increased with increasing belt depth, indicating that an increase in belt depth is beneficial to maintaining the water supply of cotton plants and improving the physiological activity of cotton leaves (Poorter et al., 2009; Sampathkumar et al., 2013; Ni et al., 2014).

Kahlaoui et al. (2011) found that subsurface drip irrigation increased tomato leaf area and chlorophyll content compared to drip irrigation. Han (2018) found that a suitable embedded belt depth (15 cm) could increase the soil volumetric water content, photosynthetic rate and stomatal conductance of pakchoi leaves. In this experiment, the net photosynthetic rate, intercellular CO_2 concentration and stomatal conductance of functional cotton leaves in D_3 from BBCH 61 to 79 were significantly higher than those in D_1 but were not significantly different from those in D_2. This indicated that increasing the depth of the embedded drip irrigation belt in the range of 10-20 cm could enhance the carbon assimilation ability of cotton leaves.

Chlorophyll fluorescence characteristics are closely related to each process of photosynthesis and can reflect the intrinsic characteristics of photosynthesis (Olaf and Jan, 1990). Liu (2020) found that an increase in the soil water content under subsurface drip irrigation could improve F_v/F_m, q_P, and ETR and reduce the NPQ of alfalfa. In this experiment, increasing the depth of the embedded drip irrigation belt significantly increased the Y_{II}, ETR, q_P and F_v/F_m of cotton leaves at BBCH 79 and reduced the NPQ at BBCH 61, which is basically consistent with the results presented by Liu. These results indicate that both increasing the depth of the embedded drip irrigation belt and increasing the soil water content can enhance the light energy conversion and utilization efficiency of cotton leaves and reduce light energy and heat dissipation.

Adjustment of the embedded drip irrigation belt depth for cotton yield

Compared with surface irrigation, subsurface drip irrigation can significantly reduce soil evaporation, realize the rational distribution of water and fertilizer in the root zone, and improve the utilization efficiency of water and fertilizer, thus achieving the purpose of increasing crop yields (Meshkat et al., 2000). Çetin and Kara (2019) evaluated the water productivity, economic water productivity and land economic productivity of cotton and concluded that a subsurface drip irrigation system with a lateral pipe depth of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

40 cm had higher economic benefits than surface drip irrigation. Çetin et al. (2021) also found that the net income under subsurface drip irrigation was significantly higher than that under surface drip irrigation. However, compared with drip irrigation under mulch, cotton cultivated without plastic mulching grew slowly in the early stage and tended to produce insufficient bolls. In this experiment, because some bolls did not open normally after spraying of the defoliating agent in D_3, the seed cotton yield increased only by 2% compared with D_2, and the difference was not significant. Liu et al. (2015) found that potato yield first increased and then decreased with increasing depth of the embedded drip irrigation belt in the range of 10–50 cm and reached the maximum yield when the depth was 30 cm. When the depth was greater than 30 cm, the potato emergence process lagged, which is consistent with the results of this study. The results indicated that the deep embedding of the drip irrigation belt would inhibit the growth and development of cotton in the early stage, delay the growth process, and then have an adverse effect on production.

Photosynthesis is the basis of yield formation. In this experiment, the correlation analysis between the photosynthetic parameters and yield showed that g_s, Y_{II}, ETR, q_P, P_N, C_i, E, and F_v/F_m were positively correlated with the seed cotton yield and biological yield and were negatively correlated with the economic coefficient. NPQ was negatively correlated with the seed cotton yield and biological yield and positively correlated with the economic coefficient. These results indicate that increasing the photosynthetic capacity of cotton leaves can further increase the biological yield and seed cotton yield but reduce its economic coefficient under the experimental conditions.

Compared with surface irrigation, subsurface drip irrigation can increase the soil moisture content in the crop root zone (Meshkat et al., 2000). According to the research of Al-Othman et al. (2020), subsurface drip irrigation without plastic mulching can reduce water consumption compared with surface drip irrigation with plastic mulching, and a proper belt depth can significantly optimize root distribution and improve root activity (Lamm et al., 2021). The depth of the embedded drip irrigation belt should be optimized to avoid damage by cultivation or other equipment and to meet the needs of seed germination and seedling growth. In addition, it should also be based on soil texture, drip irrigation belt specification, pipeline combination, irrigation quota and frequency and other factors. In this study, the optimal depth of the embedded drip irrigation belt in the experimental site was 15 cm within the range of 10–20 cm under the same soil texture, irrigation quota, irrigation frequency and other factors. However, at the determined depth of the embedded drip irrigation belt, how to optimize the irrigation mode for the growth period, tap the biological water-saving potential of cotton, and realize efficient water-saving production of cotton without plastic mulching needs further exploration.

Conclusion

Under the irrigation system in this study, the increase in the embedded drip irrigation belt depth at the experimental site was beneficial for increasing the leaf area of cotton without plastic mulching in the later growth stage, promoting the accumulation of photosynthetic pigments, improving the photosynthetic rate, transpiration rate, stomatal conductance and light energy conversion efficiency, and enhancing the photosynthetic capacity of cotton leaves. The biological yield was significantly increased under the 20 cm embedded belt depth, but there was no significant difference in seed cotton yield between the 15 cm and 20 cm depth treatments due to the significant reduction in the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

economic coefficient. Overall, D_2 (15 cm) was the most suitable embedded belt depth to maximize cotton yield without plastic mulching.

Acknowledgements. This project was supported by the National Natural Science Foundation of China (32160512) and Scientific and Technological Innovation Team of Soil Nutrient and Fertilizer Efficient Utilization in Xinjiang Academy of Agricultural Reclamation Sciences.

REFERENCES

[1] Al-Othman, A. A., Mattar, M. A., Alsamhan, M. A. (2020): Effect of mulching and subsurface drip irrigation on soil water status under arid environment. – Spanish Journal of Agricultural Research 18: 1201.

[2] Amali, S., Rolston, D. E., Fulton, A. E., Hanson, B. R., Phene, C. J., Oster, J. D. (1997): Soil water variability under subsurface drip and furrow irrigation. – Irrigation Science 17: 151-155.

[3] Ayars, J. E., Fulton, A., Taylor, B. (2015): Subsurface drip irrigation in California - here to stay? – Agricultural Water Management 157: 39-47.

[4] Çetin, O., Kara, A. (2019): Assessment of water productivity using different drip irrigation systems for cotton. – Agricultural Water Management 223: 105693.

[5] Çetin, Ö., Üzen, N., Temiz, M. G., Altunten, H. (2021): Improving cotton yield, water use and net income in different drip irrigation systems using real-time crop evapotranspiration. – Polish Journal of Environmental Studies 30: 4463-4474.

[6] Chen, Y. (2017): Discussion on the development and application of underground drip irrigation technology and existing problems. – Gansu Science and Technology 33: 128-130.

[7] Chen, Z., Tao, X., Khan, A., Tan, D. K. Y., Luo, H. (2018): Biomass accumulation, photosynthetic traits and root development of cotton as affected by irrigation and nitrogen-fertilization. – Frontiers in plant science 9: 173.

[8] Constable, G., Bange, M. (2015): The yield potential of cotton (*Gossypium hirsutum* L.). – Field Crops Research 182: 98-106.

[9] Dong, H., Li, W., Tang, W., Li, Z., Zhang, D., Niu, Y. (2005): Yield, quality and leaf senescence of cotton grown at varying planting dates and plant densities in the Yellow River Valley of China. – Field Crops Research 98: 106-115.

[10] Elmaloglou, S., Diamantopoulos, E. (2013): Simulation of soil water dynamics under subsurface drip irrigation from line sources - ScienceDirect. – Agricultural Water Management 27: 4131-4148.

[11] Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B. (2019): Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis. – Science of The Total Environment 651: 484-492.

[12] Grabow, G. L., Huffman, R. L., Evans, R. O., Jordan, D. L., Nuti, R. C. (2006): Water distribution from a subsurface drip irrigation system and dripline spacing effect on cotton yield and water use efficiency in a coastal plain soil. – Transactions of the Asabe 49: 1823-1835.

[13] Guo, X., Yang, H., Tai, J., Li, R., Zhang, M. (2020): Advances in crop shallow buried drip irrigation technology. – Journal of Inner Mongolia University for Nationalities 35: 80-84.

[14] Han, S. (2018): Soil water infiltration characteristics of different depths of moistube and its effect on crops. – Hebei University of Engineering, Hebei (in Chinese).

[15] He, H. (2001): Crop water and nitrogen use and optimum irrigation technical parameters under subsurface drip irrigation. – Northwest Agriculture & Forestry University, Shanxi (in Chinese).

[16] He, H., Wang, Z., Guo, L., Zheng, X., Zhang, J., Li, W., Fan, B. (2018): Distribution characteristics of residual film over a cotton field under long-term film mulching and drip irrigation in an oasis agroecosystem. – Soil and Tillage Research 180: 194-203.
[17] Kahlaoui, B., Hachicha, M., Rejeb, S., Rejeb, M. N., Hanchi, B., Misle, E. (2011): Effects of saline water on tomato under subsurface drip irrigation: nutritional and foliar aspects. – Journal of soil science and plant nutrition 11: 69-86.
[18] Kalfountzos, D., Alexiou, I., Kotsopoulos, S., Zavakos, G., Vyrlas, P. (2006): Effect of Subsurface Drip Irrigation on Cotton Plantations. – Water Resources Management 21: 1341-1351.
[19] Khalilian, A., Sullivan, M. J., Smith, W. B. (2000): Lateral depth placement and deep tillage effects in a subsurface drip irrigation system for cotton. – In: Proceedings of the Fourth Decennial National Irrigation Symposium, Phoenix, AZ, USA, 14–16 November: 641-646.
[20] Lamm, F. R., Colaizzi, P. D., Sorensen, R. B., Bordovsky, J. P., Dougherty, M., Balkcom, K., Zaccaria, D., Bali, K. M., Rudnick, D. R., Peters, R. T. (2021): A 2020 vision of subsurface drip irrigation in the U.S. – Transactions of the Asabe 64: 1319-1343.
[21] Li, F., Wang, P., Wang, J., Xu, J. (2004): Effects of irrigation before sowing and plastic film mulching on yield and water uptake of spring wheat in semiarid Loess Plateau of China. – Agricultural Water Management 67: 77-88.
[22] Li, X., Shi, J., Wang, S., Zuo, Q. (2017): Numerical simulation and analysis on depth of disposable tape in cotton field under subsurface drip irrigation in Xinjiang, China. – Transactions of the Chinese Society of Agricultural Machinery 48: 191-198, 222.
[23] Liu, Y. (2006): Application and effect analysis of subsurface drip irrigation in water-saving irrigation of cotton. – Water Conservancy Science and Technology and Economy 12: 831-832.
[24] Liu, J. (2020): Effects of water stress on photosynthetic physiological characteristics and quality of Alfalfa. – Gansu Agricultural University, Gansu (in Chinese).
[25] Liu, X., Wan, S., Feng, D., Jiang, S., Kang, Y., Liu, S. (2015): Response of potato yield and irrigation water use efficiency under subsurface drip irrigation at various lateral depths. – Journal of Irrigation and Drainage 34: 63-66.
[26] Maddonni, G. A., Otegui, M. E., Cirilo, A. G. (2001): Plant population density, row spacing and hybrid effects on maize canopy architecture and light attenuation. – Field Crops Research 71: 183-193.
[27] Meshkat, M., Warner, R. C., Workman, S. R. (2000): Evaporation reduction potential in an undisturbed soil irrigated with surface drip and sand tube irrigation. – Transactions of the ASAE 43: 79-86.
[28] Munger, P., Bleiholder, H., Hack, H., Hess, M., Stauß, R., van den Boom, T., Weber, E. (1998): Phenological Growth Stages of the Cotton Plant (*Gossypium hirsutum* L.): Codification and Description according to the BBCH Scale. – Journal of Agronomy and Crop Science 180: 143-149.
[29] Ni, J., Wang, W., Yu, S., Dai, S. (2014): Effects of drought stress on some physiological and biochemical indices of Kapok leaves. – Chinese Journal of Tropical Crops 35: 2020-2024.
[30] Olaf, V. K., Jan, F. H. S. (1990): The use of chlorophyll fluorescence nomenclature in plant stress physiology. – Photosynthesis Research 25: 147-150.
[31] Poorter, H., Niinemets, U., Poorter, L., Wright, I. J., Villar, R. (2009): Causes and consequences of variation in leaf mass per area (LMA): a meta-analysis. – The New phytologist 182: 565-588.
[32] Sampathkumar, T., Pandian, B. J., Jeyakumar, P., Manickasundaram, P. (2013): Effect of deficit irrigation on yield, relative leaf water content, leaf proline accumulation and chlorophyll stability index of cotton–maize cropping sequence. – Experimental Agriculture 50: 407-425.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777

[33] Shi, W. (2012): Effects of plant densities on cotton dry matter accumulation and distribution, yield and fiber quality. – Nanjing Agricultural University, Jiangsu (in Chinese).
[34] Wang, X., Li, H., Wang, Y., Wang, Y. (2020): Analysis of world cotton production and trade pattern under the background of trade dispute. – Agricultural Outlook 16: 95-99.
[35] Yao, J., Qi, Y., Li, H., Shen, Y. (2021): Effects of the irrigation quota and drip irrigation pipes spacing on growth and development of summer maize with subsurface drip irrigation. – Chinese Journal of Eco-Agriculture 29: 1502-1511.
[36] Zhang, D., Liu, H., Hu, W., Qin, X., Ma, X., Yan, C., Wang, H. (2016): The status and distribution characteristics of residual mulching film in Xinjiang, China. – Journal of Integrative Agriculture 15: 2639-2646.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37633777