

Effects of Different Irrigation Amounts on Growth, Development, and Yield Formation of Xinjiang Cotton Postprint

Authors: Zhang Hui

Date: 2023-01-17T00:00:00+00:00

Abstract

This study investigated the effects of different irrigation amounts on the growth, development, and yield formation of Xinjiang cotton, aiming to provide a theoretical basis for efficient water utilization in high-yield cotton fields in Xinjiang. A field experiment was conducted under under-mulch drip irrigation conditions, with normal irrigation amount as the control ($3071 \text{ m}^3 \cdot \text{hm}^{-2}$, I100), and three deficit gradients were established: mild deficit ($2686 \text{ m}^3 \cdot \text{hm}^{-2}$, I85), moderate deficit ($2421 \text{ m}^3 \cdot \text{hm}^{-2}$, I75), and severe deficit ($1955 \text{ m}^3 \cdot \text{hm}^{-2}$, I60). During different growth stages, cotton plant height, main stem node number, fruit branch number, boll setting and shedding characteristics were measured; at harvest stage, cotton yield components were determined, and irrigation water use efficiency was calculated. The results showed that: (1) Compared with the normal irrigation treatment, the squaring stage, flowering stage, peak boll stage, and boll opening stage of cotton under each deficit irrigation treatment were advanced by 1-2 d, 2-4 d, 3-8 d, and 4-11 d, respectively; (2) Before entering the boll stage, cotton plant height and main stem internode length exhibited a trend of first increasing and then decreasing with reduced irrigation amount, while after the boll stage, both decreased with decreasing irrigation amount; the boll number and fruit number in the middle and lower canopies of cotton decreased with reduced irrigation amount, with the fruit number in the middle canopy showing significant differences among different irrigation treatments ($P < 0.05$); (3) At harvest stage, the seed cotton yield under I100 treatment was $6090 \text{ kg} \cdot \text{hm}^{-2}$, which was 7.4%-27.3% higher than that under deficit irrigation treatments; irrigation water use efficiency increased with decreasing irrigation amount, reaching a maximum of $2.27 \text{ kg} \cdot \text{m}^{-3}$. When comprehensively considering the benefits of agricultural production, efficient water resource utilization, and ecological environment, moderate deficit irrigation is recommended for Xinjiang cotton to maintain relatively high crop yield while improving irrigation

water use efficiency, saving water resources, and achieving optimal socioeconomic and ecological environmental benefits.

Full Text

Effects of Different Irrigation Rates on Cotton Growth and Yield Formation in Xinjiang

ZHANG Hui¹², ZHANG Kai¹², CHEN Bing¹², YANG Chuan¹², LIU Ping¹²

¹College of Resources and Environmental Sciences, Xinjiang Agricultural University, Urumqi, Xinjiang 830052, China

²Xinjiang Key Laboratory of Soil and Plant Ecological Processes, Urumqi, Xinjiang 830052, China

Abstract

This study investigated the effects of different irrigation rates on cotton growth and yield formation in Xinjiang to provide a theoretical basis for efficient water utilization in high-yield cotton fields. A field experiment was conducted under mulched drip irrigation conditions, with normal irrigation ($3071 \text{ m}^3 \cdot \text{hm}^{-2}$, I_{100}) as the control. Three deficit irrigation gradients were established: mild deficit ($2686 \text{ m}^3 \cdot \text{hm}^{-2}$, I_{85}), moderate deficit ($2421 \text{ m}^3 \cdot \text{hm}^{-2}$, I_{75}), and severe deficit ($1955 \text{ m}^3 \cdot \text{hm}^{-2}$, I_{60}). Plant height, main stem node number, fruit branch number, boll setting and shedding characteristics were measured at different growth stages, yield components were determined at harvest, and irrigation water use efficiency was calculated. The results showed that: (1) Compared with normal irrigation, deficit irrigation advanced the budding, flowering, peak boll, and boll opening stages by 1-2 days, 2-4 days, 3-8 days, and 4-11 days, respectively. (2) Before the boll stage, cotton plant height and main stem internode length initially increased then decreased with reduced irrigation; after the boll stage, both decreased with reduced irrigation. The number of bolls and fruit set in the middle and lower canopy decreased with reduced irrigation, with significant differences among treatments in the middle canopy ($P < 0.05$). (3) At harvest, the seed cotton yield under I_{100} treatment was $6090 \text{ kg} \cdot \text{hm}^{-2}$, which was 7.4%-27.3% higher than deficit irrigation treatments. Irrigation water use efficiency increased with decreasing irrigation amount, reaching a maximum of $2.27 \text{ kg} \cdot \text{m}^{-3}$. In conclusion, when considering agricultural production, water resource efficiency, and ecological benefits, moderate deficit irrigation is recommended for cotton in Xinjiang to improve irrigation water use efficiency and conserve water resources while maintaining relatively high crop yields, thereby optimizing socioeconomic and ecological benefits.

Keywords: cotton; deficit irrigation; boll setting characteristics; irrigation water use efficiency

1.1 Study Area Overview

The experiment was conducted in the cotton planting area of Pengjiawan Village, Fukang City, Xinjiang (88°0 44.30" E, 44°10 21.05" N), located at the northern foot of the eastern Tianshan Mountains (Bogda Mountain). The region has a typical continental arid climate with an average annual temperature of 6.8 °C, annual sunshine duration of 2933 hours, frost-free period of 176 days, and average monthly temperature of 25.2 °C. Annual precipitation is 226.9 mm, and light and heat resources are abundant, providing suitable conditions for cotton growth. The soil type is primarily irrigated cultivated soil with a field water-holding capacity of 15.46%. Local agriculture relies mainly on river water and regional groundwater for irrigation.

1.2 Experimental Design

To clarify the effects of water regulation on cotton growth, development, and yield formation under mulched drip irrigation, as well as to understand water requirements at different growth stages, a field experiment was conducted in 2021. Cotton variety Xinluzao 61 was sown on April 20, 2021, using a “one film, one belt, two rows” planting pattern with film width of 70 cm, inter-film spacing of 40 cm, and intra-row plant spacing of 10 cm. The experiment used local normal irrigation as the control (I_{100}), with three deficit irrigation gradients: mild deficit (85% of normal irrigation, I_{85}), moderate deficit (75% of normal irrigation, I_{75}), and severe deficit (60% of normal irrigation, I_{60}). Each treatment had three replicates, with plot dimensions of 6 m × 8 m. Irrigation scheduling followed local farmer practices, with 11 irrigation events throughout the growth season (Table 1). Fertilizer application was consistent across all plots: phosphorus fertilizer (P_2O_5) at 75 kg · hm⁻², nitrogen fertilizer (urea) at 250 kg · hm⁻², and potassium fertilizer (K_2SO_4) at 150 kg · hm⁻², applied in six splits through fertigation (Table 2). Except for irrigation amounts, all other field management and agronomic practices followed conventional practices.

1.3 Measurement Methods

Growth Stage Investigation: After emergence, 10 consecutive cotton plants (5 from inner and outer rows each) were selected in each plot to investigate growth progression (seedling, budding, flowering, peak boll, and boll opening stages) and record the dates when cotton entered each growth stage.

Growth and Development Measurements: Throughout the growing season, growth traits were measured on the marked plants. Starting after the first irrigation treatment, plant height (from cotyledon node to main stem apex), main stem node number, fruit branch number, and fruiting node position were recorded. The number of squares, flowers, and bolls and their abscission were measured on June 30, July 15, July 30, August 15, and August 30. At the boll opening stage, boll setting, abscission, and fruiting characteristics were measured in the upper (top 1/3 of fruit branches), middle (middle 1/3), and lower

(bottom 1/3) canopy layers.

Yield Measurement: At harvest, three 1 m × 1 m sampling areas with uniform plant growth were selected in each plot to record plant density and bolls per plant. Thirty bolls were randomly collected from upper, middle, and lower canopy positions in each plot, air-dried in mesh bags, and weighed to calculate seed cotton yield per unit area.

Irrigation Water Use Efficiency Calculation:

$$IWUE = Y / I$$

where IWUE is irrigation water use efficiency ($\text{kg} \cdot \text{m}^{-3}$), Y is seed cotton yield ($\text{kg} \cdot \text{hm}^{-2}$), and I is total drip irrigation amount during the growth season ($\text{m}^3 \cdot \text{hm}^{-2}$).

Data Analysis: Experimental data are presented as mean \pm standard error. One-way ANOVA was used to compare differences in measured indicators among treatments, with multiple comparisons performed using LSD test at $P < 0.05$ significance level. Data were processed using Microsoft Excel 2019 and analyzed using SPSS 25.0 (SPSS Inc., Chicago, IL, USA), with figures prepared using Origin 2021.

2.1.1 Growth Stages

As shown in Table 3, deficit irrigation treatments advanced cotton phenological stages compared with the control. With increasing water deficit, the budding, flowering, peak boll, and boll opening stages occurred 4-11 days, 3-8 days, 2-4 days, and 1-2 days earlier than the control, respectively.

2.1.2 Growth and Development Process

Plant height and main stem internode length reflect cotton growth status. Figure 1 shows that throughout the growing season, cotton plant height and main stem internode length initially increased rapidly then gradually plateaued. Before the boll stage, plant height and internode length showed a trend of first increasing then decreasing with reduced irrigation. After July 30, plant height decreased with reduced irrigation, while internode length showed no significant change. Fruiting node position remained relatively stable, while fruit branch number increased rapidly then plateaued. After the flowering stage, fruit branch number decreased with reduced irrigation, reaching significant differences among treatments by the peak boll stage on August 15 ($P < 0.05$).

2.2.1 Square and Boll Number per Plant and Water Load at Different Growth Stages

The response of squares and bolls per plant to irrigation amount varied across growth stages. During the budding and flowering stages, irrigation amount had

little effect on square and boll growth. However, during the young boll and mature boll stages, boll number decreased significantly with reduced irrigation (Figure 2), indicating that cotton is more sensitive to water during these stages. Additionally, the water load per unit water amount (number of squares and bolls per m^3 of water) increased with reduced irrigation, with the I_{60} treatment showing the highest values, particularly during budding and flowering stages (Figure 2).

2.2.3 Fruit Branch Ratio and Boll Abscission Rate

The fruit branch ratio (ratio of total fruiting nodes to fruit branch number) indicates the average number of fruiting nodes per fruit branch. A higher ratio means more fruiting nodes per branch. As shown in Figure 4, the middle and lower canopy layers had larger fruit branch ratios than the upper canopy. In the upper canopy, the fruit branch ratio initially increased then decreased with reduced irrigation, with significant differences among treatments ($P < 0.05$), peaking at 1.67 under I_{85} treatment.

Boll abscission rates across canopy layers followed the pattern: upper > middle > lower (Figure 5). In the upper canopy, boll abscission rate was highest under I_{100} (81.19%) and lowest under I_{85} (73.6%). In the middle canopy, rates were 59.59% (I_{100}), 47.9% (I_{85}), and 36.47% (I_{75}). In the lower canopy, abscission rate showed a decreasing then increasing trend with reduced irrigation.

2.3 Effects of Different Irrigation Treatments on Cotton Dry Matter Accumulation and Distribution

Irrigation amount significantly affected dry matter accumulation in cotton organs. At harvest, total dry matter accumulation followed the order: $I_{100} > I_{85} > I_{75} > I_{60}$ (Table 4), indicating that higher irrigation promoted biomass production. Regarding dry matter distribution, significant differences existed between normal and deficit irrigation treatments ($P < 0.05$). Reproductive organ dry matter decreased with increasing water deficit, while vegetative organ dry matter showed the opposite trend. The proportion of dry matter allocated to reproductive organs decreased with water deficit, following the order: $I_{100} > I_{75} > I_{85} > I_{60}$.

2.4 Effects of Different Irrigation Treatments on Cotton Yield and Yield Components

Significant analysis of bolls per plant, boll weight, and seed cotton yield showed that normal irrigation produced 3.5%–24.9% more bolls per plant and 7.4%–27.3% higher seed cotton yield than deficit irrigation treatments ($P < 0.05$) (Table 5). Boll weight showed little effect on seed cotton yield. These results indicate that water primarily affects yield by influencing bolls per plant.

2.5 Correlation Analysis Between Cotton Growth Process and Yield Components Under Different Irrigation Treatments

Correlation analysis revealed that among growth indicators, fruit branch ratio had the strongest positive correlation with bolls per plant ($r = 0.83$), followed by plant height and main stem internode length. Boll abscission rate showed a significant negative correlation with bolls per plant ($P < 0.01$). Fruit branch ratio and abscission rate had the strongest correlation with boll weight ($r = 0.71$ and $r = 0.70$, respectively). The study also found that the I_{85} treatment had higher plant height and earlier fruit branch development during the budding stage, similar to findings by Zhang Shimin and Liu Suhua et al. This may be because moderate deficit irrigation reduces soil water content, favoring early spring soil temperature increase and cotton growth, suggesting that moderate deficit irrigation during the budding stage could benefit subsequent boll development. After square initiation, fruit branch growth accelerated, and during the young boll stage, fruit branch growth was sensitive to water, so adequate irrigation during this period could promote plant height and fruit branch number.

2.6 Relationship Between Irrigation Water Use Efficiency and Yield Under Different Irrigation Treatments

Analysis of seed cotton yield and irrigation water use efficiency (IWUE) showed that seed cotton yield increased gradually with irrigation amount, reaching a maximum of $6090 \text{ kg} \cdot \text{hm}^{-2}$ under full irrigation. Conversely, IWUE decreased with increasing irrigation amount, reaching a maximum of $2.27 \text{ kg} \cdot \text{m}^{-3}$ under deficit irrigation I_{60} treatment (Figure 6).

3.1 Effects of Different Irrigation Amounts on Cotton Growth and Development

In arid cotton-growing regions, irrigation is an effective means to regulate cotton growth and development, significantly affecting yield and quality. This study showed that moderate deficit irrigation created water stress that promoted earlier transition to reproductive growth, increasing boll growth duration and single boll weight. This is advantageous for high yields in Xinjiang's short frost-free period. However, excessive deficit irrigation inhibited growth, resulting in shorter plants, fewer fruit branches and main stem nodes, and shorter internodes, consistent with Zhang et al.'s findings. The study also found that the I_{85} treatment had higher plant height and earlier fruit branch development during the budding stage, possibly because moderate deficit irrigation reduced soil water content and favored early spring temperature increase, providing a foundation for boll development during the flowering and boll stage.

3.2 Effects of Different Irrigation Amounts on Boll Setting and Square/Boll Abscission Characteristics

Fruit branch number and fruit branch ratio are direct factors affecting boll number. This study found that fruit branch ratio and boll number in middle and lower canopy layers showed no significant differences among treatments, while upper canopy fruit branch ratio and boll number initially increased then decreased with irrigation amount, indicating that moderate deficit irrigation could increase boll number by improving fruit branch ratio, while excessive deficit or over-irrigation reduced both.

Fruit set in middle and lower canopy layers was significantly higher than in the upper canopy, with upper canopy fruit set showing significant differences among irrigation treatments. This suggests that intensified water deficit severely affected upper canopy fruit set, likely because growth-limiting factors differ across growth stages. Lower canopy bolls (pre-summer bolls) develop mainly in spring when temperature is the primary control factor with relatively low water consumption, so irrigation amount has limited effect. In contrast, middle and upper canopy bolls (summer bolls) develop during hot weather with high water consumption, making them more sensitive to irrigation amount. Therefore, water management during hot weather periods requires special attention.

The higher boll number in the lower canopy also relates to longer boll growth duration and lower abscission rates. In middle and lower canopy layers, boll abscission rates increased slightly with water deficit intensity, consistent with Shen et al., likely representing cotton's self-regulation to cope with water stress. Under adequate fruit set conditions, shedding of excess squares/bolls can prevent nutrient competition and ensure development of effective bolls.

3.3 Effects of Different Irrigation Treatments on Cotton Yield and Irrigation Water Use Efficiency

Deficit irrigation affects seed cotton yield, with bolls per plant being most significantly reduced. Water deficit during peak flowering and young boll stages severely impacts bolls per plant and seed cotton yield, consistent with Shen et al. This is because peak flowering is a critical period when vegetative and reproductive growth occur simultaneously with peak water demand. Excessive water deficit during this stage disrupts normal physiological metabolism, causing massive square/boll abscission and reducing yield. However, excessive irrigation can also reduce yield by causing imbalance between vegetative and reproductive growth, with resources over-allocated to vegetative growth at the expense of reproductive development, leading to late maturity and yield reduction.

There exists a trade-off between irrigation water use efficiency and seed cotton yield (Figure 6), consistent with Shen et al. Considering agricultural production, water resource efficiency, and ecological benefits, moderate deficit irrigation is recommended for cotton in Xinjiang to improve irrigation water use efficiency and conserve water while maintaining relatively high yields, thereby optimizing

socioeconomic and ecological benefits.

4 Conclusion

This study investigated the effects of different irrigation rates on cotton growth, yield formation, and irrigation water use efficiency in Xinjiang. The results indicate that: (1) Deficit irrigation advanced flowering and boll setting, shortening the entire growth period. (2) However, excessive water deficit affected square/boll development, reducing fruit branch/node differentiation and boll formation, with upper and middle canopy boll setting and fruit set being more sensitive to water. (3) Regarding yield components, deficit irrigation reduced yield primarily by decreasing bolls per plant. (4) Irrigation water use efficiency increased while seed cotton yield decreased with reduced irrigation amount, indicating a trade-off between the two. Therefore, moderate deficit irrigation is recommended for cotton in Xinjiang to achieve optimal socioeconomic and ecological benefits while ensuring relatively high crop yields and improved water use efficiency.

References

- [1] Akram H M, Ali A, Sattar A, et al. Impact of water-deficit stress on various physiological and agronomic traits of three Basmati rice (*Oryza sativa* L.) cultivars[J]. *Journal of Animal and Plant Sciences*, 2013, 23(5): 1415-1423.
- [2] Liu Lei, Chen Yuanhan, Lei Zixiang. Study on high quality development of cotton industry in Xinjiang[J]. *Macroeconomic Management*, 2021(10): 77-83, 90.
- [3] Zheng Yuanfang. Distribution and vulnerability assessment of water resources in Xinjiang[J]. *Shaanxi Water Resources*, 2018(S1): 39-41.
- [4] Liu Xiang, Zhang Fucang, Xiang Youzhen, et al. Effects of deficit irrigation on cotton growth and water use in southern Xinjiang of China[J]. *Journal of Drainage and Irrigation Machinery Engineering*, 2020, 38(12): 1270-1276.
- [5] Fan Zhichao, Zhang Jusong, Shi Junyi, et al. Effect of soil water content on photosynthetic and yield of drip irrigation in cotton under regulated deficit irrigation[J]. *Acta Agriculturae Boreali-occidentalis Sinica*, 2017, 26(10): 1461-1469.
- [6] Dong Qianqian, Fan Wenbo, Xu Zhongyu, et al. Experimental study on the effect of drip irrigation water volume and soil temperature on CO₂ concentration in soil profile of barrel-planted cotton[J]. *Arid Zone Research*, 2020, 37(3): 636-644.

- [7] Yao Qingqing, Sun Huijian, Ma Xingwang, et al. Effects of reduced amount nitrogen application on cotton aboveground dry matter accumulation, distribution and yield[J]. Xinjiang Agricultural Sciences, 2021, 58(8): 1398-1405.
- [8] Tian Yousheng, Fan Shuli, Pang Zhaoyou, et al. Effects of drought stress in the whole period on cotton morphology, physiology, photosynthesis and yield[J]. Acta Agriculturae Boreal Sinica, 2017, 32(5): 224-231.
- [9] He Peiyun, Zhang Yu, Zhou Liang, et al. Effects of drought stress and nitrogen fertilizer regulation on morphology, physiological characteristics and yield of *Fagopyrum tataricum*[J]. Chinese Journal of Applied and Environmental Biology, 2022, 28(1): 128-134.
- [10] Chen Y Z, Dong H Z. Mechanisms and regulation of senescence and maturity performance in cotton[J]. Field Crops Research, 2016, 189: 1-9.
- [11] Du Gangfeng, Wang Jiangtao, Sun Xuebing, et al. Effects of irrigation method and irrigation amount on cotton crown leaf-boll configuration[J]. Xinjiang Agricultural Science, 2019, 56(7): 1177-1186.
- [12] Feng L, Bufon V B, Mills C I, et al. Effects of irrigation and plant density on cotton within-boll yield components[J]. Agronomy Journal, 2010, 102: 1032-1036.
- [13] Feng L, Mathis G, Ritchie G, et al. Optimizing irrigation and plant density for improved cotton yield and fiber quality[J]. Field Crops Research, 2016, 197: 1-9.
- [14] Wang Yun. Effects of Water Deficit at Different Growth Stages on the Growth and Development of Potted Cotton[D]. Wuhan: Huazhong Agricultural University, 2016.
- [15] Zhang Shimin. Effects of Regulated Deficit Irrigation on Growth Physiology and Yield of Cotton[D]. Aral: Tarim University, 2017.
- [16] Jiang Menghui, Sun Fenglei, Yang Yang, et al. Identification and evaluation of drought resistance of upland-island recombination inbred line population at blossoming and boll forming stages[J]. Arid Zone Research, 2020, 37(6): 1635-1643.
- [17] Liu Suhua, Peng Yan, Peng Xiaofeng, et al. Effects of regulated deficit irrigation and plant density on plant growth and yield and fiber quality of cotton in dry land area[J]. Cotton Science, 2016, 28(2): 184-188.
- [18] Wang Rui. Ecological and Physiological Responses of Cotton to Drought During Flowering and Boll Forming Period[D]. Nanjing: Nanjing Agricultural University, 2016.
- [19] Li Zhibo, Xu Jianwei, Li Heng, et al. Effect of prolonged drought during late growth stage on growth of cotton and evaluation of its drought resistance in North Xinjiang[J]. Agricultural Research in the Arid Areas, 2014, 32(3): 45-49, 82.

- [20] Shen Xiaojun, Zhang Jiyang, Liu Zugui, et al. Effects of different water treatments on yield and water use efficiency of cotton with drip irrigation under film mulch[J]. *Agricultural Research in the Arid Areas*, 2012, 30(2): 118-124.
- [21] Zhang D, Luo Z, Liu S, et al. Effects of deficit irrigation and plant density for improved cotton yield and fiber quality[J]. *Agronomy Journal*, 2014, 106: 1111-1118.
- [22] Niu Yuan, Yang Xiangkun, Zhang Zhanqin, et al. Effects of different irrigation amounts on dry matter accumulation of cotton under film uncovering cultivation[J]. *Xinjiang Agricultural Science*, 2022, 59(2): 291-301.
- [23] Liang Fubin. Effects of Water Deficit on Photosynthetic Characteristic and Water Use Efficiency of Boll-Leaf System of Cotton[D]. Shihezi: Shihezi University, 2019.
- [24] Dai Jianmin, He Qingyu, Xie Ling, et al. Compensation effect of nitrogen fertilizer post-shift on water-deficient cotton yield at different stages[J]. *Arid Zone Research*, 2022, 39(3): 986-995.
- [25] Wang Ning, Feng Keyun, Nan Hongyu, et al. Effects of combined application of organic fertilizer and chemical fertilizer on root characteristics and yield of cotton under different water conditions[J]. *Scientia Agricultura Sinica*, 2022, 55(11): 2187-2201.
- [26] Shen Xiaojun, Zhang Jiyang, Sun Jingsheng, et al. Effects of different water treatments on yield and water use of transplanted cotton following wheat harvest[J]. *Transactions of the Chinese Society for Agricultural Machinery*, 2014, 45(6): 150-160.
- [27] Zhai Zhongmin, Shi Wenjuan, Zhang Yanchao, et al. Effect of water, nitrogen and salt regulation on cotton yield under mulch film drip irrigation and its coupled model[J]. *Journal of Drainage and Irrigation Machinery Engineering*, 2022, 40(7): 721-728.
- [28] Ji Qingyuan, Zhang Fucang, Xiao Chao, et al. Effects of soil water regulation on cotton growth and soil water-salt distribution[J]. *Journal of Northwest A&F University (Natural Science Edition)*, 2023, 51(1): 1-12.
- [29] Luo Honghai, Zhu Jianjun, Zhang Wangfeng. Effect of water around root zone on dry matter production and water use efficiency of cotton under drip irrigation[J]. *Xinjiang Agricultural Science*, 2011, 48(4): 622-628.
- [30] Liu Xueyan, Ding Bangxin, Bai Yungang, et al. Effects of drip irrigation under brackish water film on cotton growth and yield[J]. *Arid Zone Research*, 2020, 37(6): 1627-1634.
- [31] Shen Xiaojun, Zhang Jiyang, Sun Jingsheng, et al. Effects of drip irrigation pattern and irrigation lower limit on yield and quality of cotton[J]. *Journal of Drainage and Irrigation Machinery Engineering*, 2014, 32(8): 711-718.

[32] Xie Tingting, Shan Lishan, Su Peixi. Effects of drought stress on cotton growth and intraspecific relationship under different nitrogen application rates[J]. Chinese Journal of Eco-Agriculture, 2020, 28(5): 643-651.

[33] Gong Yutian, Sun Suhong, Yan Hongwei. Effects of water stress on agronomic traits of maize at different growth stages[J]. Water Saving Irrigation, 2017(5): 34-36, 41.

[34] Yang Tiantian. Growth Simulation and Yield Evaluation of Membrane-less Cotton under Different Irrigation Gradients[D]. Aral: Tarim University, 2022.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv –Machine translation. Verify with original.