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High-Yield Cotton Cultivation Practices in Arid Regions

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Abstract This study focused on cotton cultivation in arid regions and analyzed the key factors influencing high cotton yield and water use efficiency. Results showed significant differences in yield and drought resistance between irrigated and non-irrigated cotton varieties. Among them, 'Tamcot CD3H' and 'TX-CABUCS-2-1-83' maintained high yields even without irrigation, demonstrating good drought tolerance. Moderately reducing irrigation (controlling to 80% of field capacity) can conserve water and improve water use efficiency while maintaining yield. Controlling irrigation timing and water temperature is also crucial, with irrigation at night and water temperatures maintained between 25 ℃ and 28 ℃. Using treated wastewater for irrigation in arid regions has not only increased cotton yields but also reduced reliance on chemical fertilizers and lowered costs. Adopting partial root zone dry irrigation and mulching has reduced water use while also improving yield and quality. This study proposes a series of effective practices for cotton cultivation in arid regions and introduces several promising technologies and regulatory measures.

Keywords High-yield cotton; Water use efficiency; Arid regions; Genetic variation; Under-irrigation; Wastewater irrigation; Partial root zone drought; Mulching technology

1 Introduction

Cotton (*Gossypium* spp.) is one of the most widely cultivated fiber crops in the world, playing a vital role in the agricultural economies of many countries. In arid regions, cotton is a primary source of income and employment for farmers. Compared to other crops, cotton is more adaptable to the environment and can grow stably in areas with challenging climatic conditions. In inland northwest my country, cotton cultivation covers a large area, making it a major national cotton production base and a significant influence on the global cotton market (Feng et al., 2017). The southern highlands of the United States are also exploring cotton cultivation models suitable for semi-arid conditions and are a key area for optimizing drought-resistant cotton cultivation techniques (Mauget et al., 2020).

However, cotton planting in arid areas faces many problems. The first is water shortage. Although cotton has good stress resistance, its water demand is not low, so the shortage of water resources restricts the yield. In order to save water, drip irrigation and reclaimed water irrigation are widely used locally (De Araújo et al., 2022; Wu et al., 2023). In addition to water, extreme temperature and soil salinity are also prominent. High temperature will inhibit the growth and development of cotton and reduce the yield per unit area; However, high soil salinity will damage soil structure and affect nutrient absorption (Shareef et al., 2018; Iqbal et al., 2021). In recent years, climate change has made precipitation distribution more unstable, which poses a new challenge to agriculture in arid areas. Agricultural planting needs stronger stress resistance and more reasonable management mode (Li et al., 2021).

This study focused on the cultivation methods of High-yield Cotton in arid areas, focused on exploring and evaluating a variety of water-saving management technologies, including irrigation timing, water temperature control and other measures, and analyzed their impact on cotton growth and yield. At the same time, the study will also cover the actual effects of cultivation methods, partial root zone drought treatment, and the use of reclaimed water irrigation and other strategies in different climate situations, providing specific and practical technical paths for cotton planting in arid areas, and solving the problems of water resources shortage, high temperature stress and saline alkali soil.

2 Agronomic Measures for High-Yield Cotton Cultivation in Arid Areas

2.1 Soil preparation

To plant cotton in arid areas, first of all, the soil should be well prepared. The problem here is usually that the salt content in the soil is too high, which will affect the growth of cotton. The soil can be improved by furrow sowing combined with plastic film mulching, so that the root environment is more suitable for cotton growth. These practices can reduce the osmotic pressure problem and ion toxicity caused by too high salinity, which is conducive to plant health and increase yield. Planting more densely, applying fertilizer scientifically, and using plant growth regulators can also enhance the resistance of cotton to saline alkali and make cotton grow better (Zhang et al., 2023).

Sandy soils are common in arid regions, and nutrients are easily lost, especially nitrogen fertilizer, which is most easily washed away by water. Using traditional broadcast fertilization methods results in a significant amount of fertilizer wasted. A better approach is "side-drain urea application" (SDM), which involves applying fertilizer next to the crop after irrigation. This practice retains nitrogen near the roots, preventing it from escaping. Cotton absorbs more nitrogen, naturally leading to faster growth, more bolls, and higher yields (Shareef et al., 2019).

2.2 Irrigation method

Water is a critical resource in arid regions, so it should be used sparingly. Drip irrigation is a very practical method, delivering water directly to the roots, preventing it from being wasted through evaporation or surface runoff. Combining fertilization and irrigation—known as "fertigation"—can achieve even greater results. Using recommended urea dosages with drip irrigation can ensure yield without increasing greenhouse gas N_2O emissions (Li et al., 2020).

In order to make irrigation more reasonable, the "Decision Support System for Irrigation Scheduling" (DSSIS) can also be used. This system will refer to weather forecast and soil water shortage to arrange when watering is more appropriate. By planting cotton in this way, the cotton yield can be increased by up to 32%, and the cotton yield per ton of aquatic products is also increased by 20%, which is more efficient than the traditional method of relying only on soil moisture sensors (Chen et al., 2020).

2.3 Crop rotation and intercropping

If cotton is grown year after year, the soil will become "tired" and prone to pests and diseases. Therefore, it can be rotated with other crops. For example, beans can fix nitrogen, enriching the soil with nitrogen and eliminating the need for constant fertilizers (Shareef et al., 2019). Intercropping with other crops can also help break the pest-disease cycle and provide habitats for beneficial insects, naturally reducing pests.

Intercropping also increases organic matter in the soil, improves soil structure, enhances soil microbial activity, and facilitates nutrient cycling. It also enhances water infiltration, making it less susceptible to soil erosion by rainwater and maintaining soil moisture. These factors are beneficial for cotton cultivation in arid regions, ensuring long-term stable and sustainable yields.

2.4 Water management

In some areas, groundwater is highly saline, making it unsuitable for direct irrigation. In these cases, desalination can be used to remove the excess salt, making the water suitable for farming. While this technology is costly, it is sometimes the only option in extremely arid areas close to the sea (Chen et al., 2020).

In some places, groundwater is too salty to be directly used for irrigation. At this time, seawater desalination technology can be used to remove the excess salt, so that the water can be used for farming. Although the cost of this technology is high, it is sometimes the only way in extreme drought and offshore areas.

3 Selection of Cotton Varieties

3.1 Drought resistant varieties

In arid areas, to grow good cotton, varieties must be drought resistant. Cotton materials such as CQJ-5, Xin Lu Zao 45, bellsno, Zhong r 2016 and Nd 359-5 can still maintain high yield under water shortage conditions, and their geometric average yield (GMP) and stress resistance index (STI) are good (Sun et al., 2023b). These are excellent varieties selected under normal and arid environment, which are suitable for drought prone areas.

Another approach is genetic modification, such as introducing the *OsSIZ1* gene from rice into cotton. This transgenic cotton exhibits enhanced photosynthesis and growth rate under high-temperature drought conditions, even increasing yield with reduced watering (Mishra et al., 2017).

3.2 Genetic engineering of cotton

Genetic engineering can make cotton more adaptable to drought conditions. In addition to the *OsSIZ1* gene mentioned above, other studies have used the *DgCspC* gene from the radiation-resistant bacterium *Deinococcus gobiensis*, with remarkable results. Transgenic cotton plants grown taller, had larger leaves, and exhibited improved physiological health in water-stressed and saline-alkaline environments, significantly stronger than non-transgenic control plants (Figure 1) (Xia et al., 2022).

3.3 Adapt to local conditions

If you want cotton to grow well, you have to choose varieties suitable for local conditions. For example, researchers in Pakistan tested 40 cotton varieties, compared them under normal and drought conditions, and finally screened out 10 varieties with good performance, including VH-144 and IUB-212 (Ullah et al., 2022).

Genomics tools are increasingly used. Genome wide association analysis (GWAS) can find out which genes or SNPs are related to the yield of cotton under drought. In China, a study based on 150 cotton varieties found some important genetic markers (Sun et al., 2023a). These results can be directly used in breeding and improve the growth performance of cotton in arid areas.

4 Climatic and Environmental Factors

4.1 Microclimate and local climate conditions

To grow cotton in arid areas, you should first understand the local microclimate. Microclimate refers to climate conditions that are more local and have more detailed impacts than large-scale weather. It may vary depending on terrain, wind direction or vegetation density. For example, the change of cotton planting density will change the light, temperature and humidity inside the cotton field.

A study from Xinjiang, China, found that when planted more densely, the cotton canopy can block more light, and at the same time increase the humidity and reduce the temperature in the field. These changes have an impact on the number and weight of cotton bolls and affect the final yield (Zhang et al., 2021).

In addition to planting density, planting time should also be determined according to local climate. In a simulation of the Southern Plateau of the United States, early sowing can make cotton use of more suitable weather at key growth stages, so the median yield is higher (Mauget et al., 2020). If farmers have the local microclimate data, they can make more reasonable arrangements in sowing, planting, irrigation and other aspects.

4.2 Heat resistance and water shortage response

In arid areas, cotton is vulnerable to high temperature and water shortage. Some studies have simulated the Root Zone Water Quality Model (RZWQM2) and found that proper reduction of irrigation (also known as under irrigation) can save water resources without affecting the yield. Under the situation of higher temperature and higher carbon dioxide concentration in the future, this irrigation method can also improve water use efficiency and bring economic benefits (Chen et al., 2023).

It is also important to choose cotton varieties that are more resistant to high temperatures. For example, in a simulation of the lowland desert in Arizona, scientists found that if the temperature rises too fast in the future, cotton production will be reduced during flowering or Bolling. However, if the varieties with heat resistance are replaced, and the planting time is changed or the water use efficiency is improved, a certain yield can still be maintained (ayankojo et al., 2020).

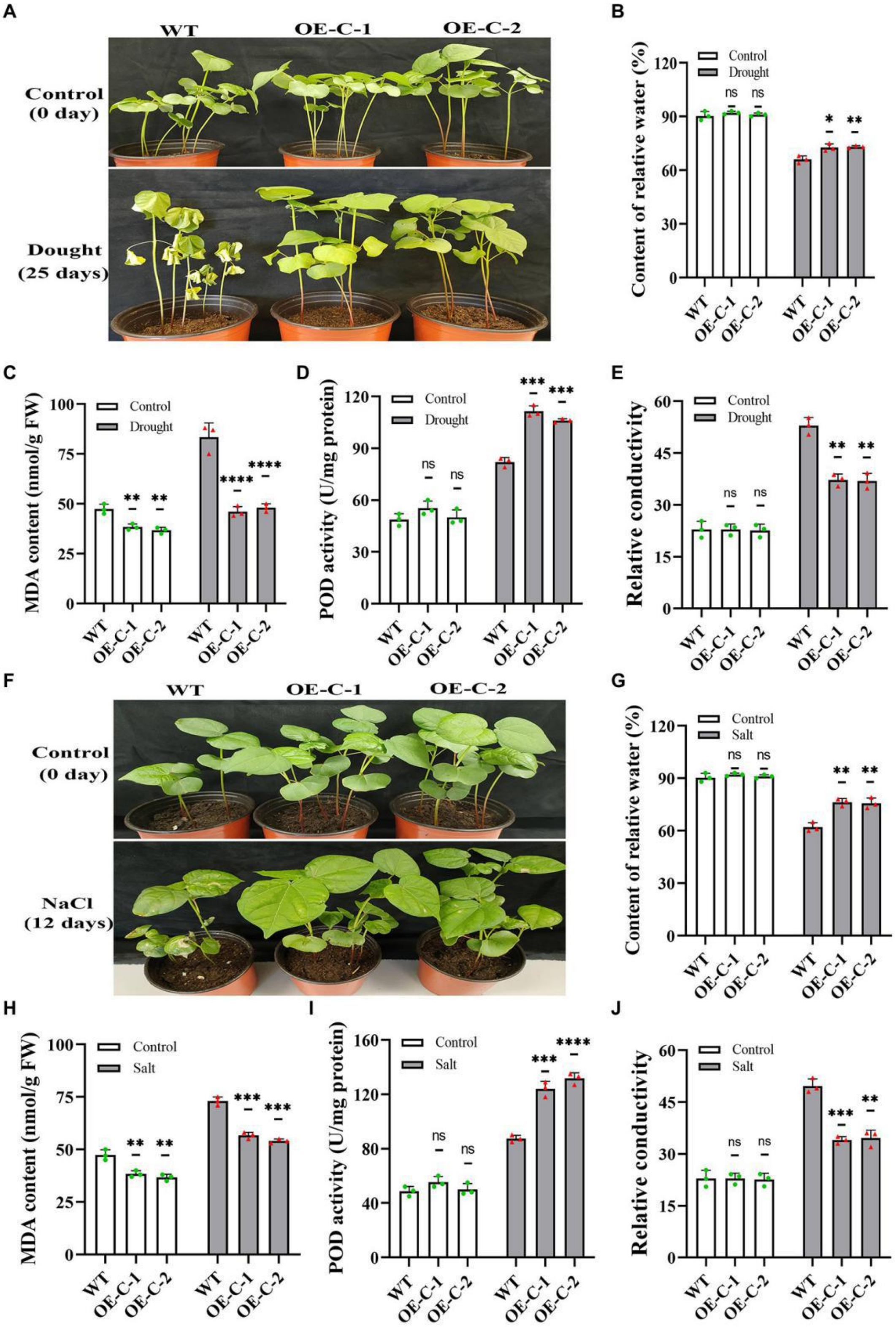

Figure 1 Phenotype and physiological indexes of DgCspC transgenic cotton under drought and salt stress (Adopted from Xia et al., 2022)

Image caption: (A) Phenotype of transgenic and wild-type cotton line under natural drought and rehydration; (B) relative water content; (C) MDA content; (D) POD content; (E) relative conductivity; (F) phenotype of transgenic and wild-type cotton lines under salt treatment; (G) relative water content under salt stress. (H) MDA content under salt stress; (I) POD content under salt stress; (J) relative conductivity under salt stress; Asterisks indicate significant differences between WT and the OE-C-1/ OE-C-2 transgenic lines. (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$ for comparisons between the transgenic lines and wild-type plants by Student's t-tests) (Adopted from Xia et al., 2022)

4.3 Specific impacts of climate change

Climate change has affected cotton planting and may also bring some new situations. For example, the research in Xinjiang shows that the temperature rise makes the germination and flowering of cotton become earlier, and the overall growth cycle becomes longer. Although temperature rise in some stages (such as initial germination) is not conducive to cotton, high temperature in some stages (such as flowering to boll maturity) is conducive to yield increase (Huang and Ji, 2015).

Future atmospheric carbon dioxide levels may continue to rise, creating a dual impact on cotton cultivation. A global analysis reveals that each 1 ℃ temperature increase reduces cotton yields by approximately 1.64%, while a 1 ppm rise in CO_2 concentration could boost production by 0.05% (Li et al., 2021). Although rising temperatures pose challenges for cotton, with proper management practices, appropriate crop varieties, and strategic adaptation to rising CO_2 concentrations, stable cotton production remains achievable.

5 Technology and Practice Innovation

5.1 Precision agriculture

In arid areas, precision agriculture technology has played a great role in cotton planting. Farmers can now use sensors, unmanned aerial vehicles and artificial intelligence tools to master soil moisture, vegetation and evaporation in real time, so as to arrange irrigation and fertilization more reasonably. For example, the normalized difference vegetation index (NDVI) obtained by the time domain reflectance (TDR) sensor and sentinel 2 satellite can accurately monitor water and crop growth, which helps to improve the water and fertilizer use efficiency of cotton (Figure 2) (Filintas et al., 2022).

Drones equipped with multispectral cameras can capture high-resolution field images. By analyzing the data through AI, they identify problematic areas to determine where irrigation or pest control is needed. Machine learning models can also predict crop yields and disease outbreaks based on soil conditions and weather patterns, helping farmers prepare in advance and reduce unnecessary investments (Prasad et al., 2019; Sharma et al., 2021).

5.2 Soil and moisture monitoring technology

To plant cotton in arid areas, we must have a good grasp of soil and moisture. Current technologies include soil moisture sensors, temperature meters and nutrient analysis equipment. The water sensor can feed back the amount of water in the soil in real time, so that the watering time can be accurately arranged to avoid excessive or insufficient water. The combination of this sensor and decision-making system can increase cotton yield and improve water utilization (Chen et al., 2020).

Temperature sensors are also very useful. They can ensure that the water temperature and soil temperature are in the range suitable for cotton growth. Studies have pointed out that if irrigated at night and controlled water temperature, photosynthesis and nitrogen absorption can be improved, thereby increasing yield (Wu et al., 2023). Understanding what elements are missing in the soil through the nutrient analyzer, and then carrying out targeted fertilization can not only improve fertilizer efficiency, but also reduce environmental pollution (Neuphane et al., 2021; Filintas et al., 2022).

5.3 Pest management

Integrated Pest Management (IPM) serves as a crucial approach to reduce pesticide use. This method combines multiple strategies including beneficial insect release, crop rotation, mechanical control, and precision application. Modern precision agriculture tools like drones have been integrated, enabling aerial pest monitoring and targeted spraying where needed—eliminating the need for full-field coverage, thereby reducing chemical usage (Prasad et al., 2019).

Artificial intelligence systems can predict future risks by analyzing historical pest data and weather patterns, enabling farmers to take preemptive measures and minimize losses. Furthermore, integrating beneficial insects with cultivation techniques like crop rotation and intercropping can effectively reduce pest and disease issues. These methods not only protect crops but also decrease reliance on chemical pesticides, ultimately contributing to sustainable agricultural development (Sharma et al., 2021; Baig et al., 2023).

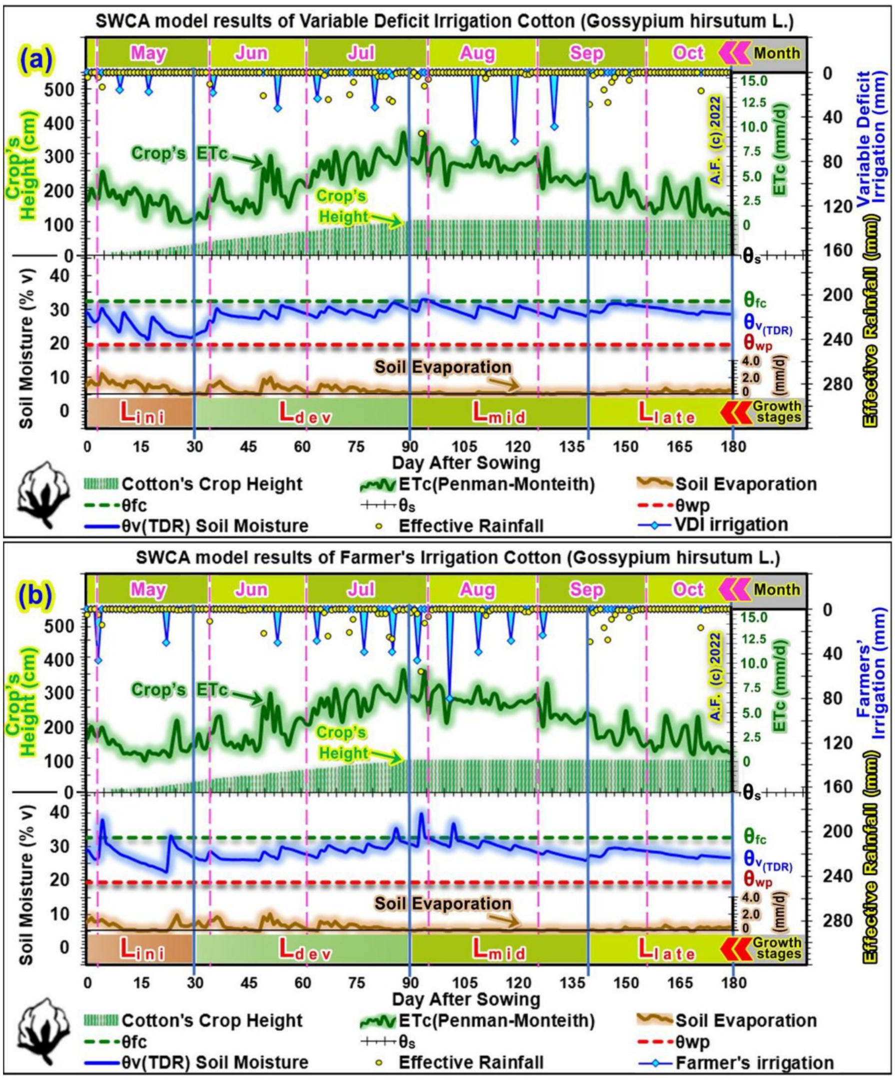

Figure 2 The daily soil-water-crop-atmosphere model results and the soil moisture measurement results for the four cotton growth stages of: (a) IR1:VDI-2 irrigation treatment and (b) treatment for IR2:FI-2 farmers' common irrigation practices (Adopted from Filintas et al., 2022)

6 Case Studies

6.1 Case 1: high yield cotton planting practice in arid areas of Xinjiang

In Shihezi, a typical arid area in Xinjiang, researchers carried out field experiments for four consecutive years to study the effects of different row spacing and irrigation amount on cotton yield and soil moisture. The results showed that using conventional drip irrigation (CI) and high density planting combination ($RS_{66+10}H$), the yield of seeds and cotton lint were the highest. Compared with limited drip irrigation (LI), this method increased seed yield by 6.6%~18.3%, and cotton lint yield by 7.1%~20.8%. In addition, under the premise of conventional drip irrigation, RS76L planting method can not only maintain high yield, but also effectively reduce soil water consumption, so it is recommended for High-yield Cotton Cultivation in Northern Xinjiang (Figure 3) (Zuo et al., 2023).

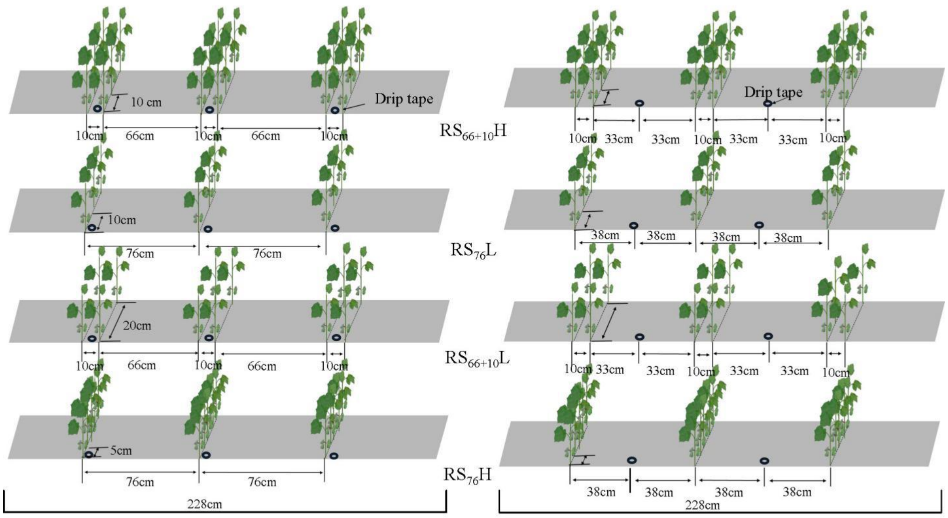

Figure 3 Schematic of four different planting densities of cotton (*Gossypium hirsutum*) evaluated during this study on cotton cultivation in Xinjiang, China (Adopted from Zuo et al., 2023)

Image caption: Where $RS_{66+10}H$ has 66+10 cm row spacing with 26 plants m^{-2} (high density), $RS_{76}H$, where 76 cm row spacing with 26 plants m^{-2} (high density), $RS_{76}L$ has 76 cm row spacing with 13 plants m^{-2} (low density), and $RS_{66+10}L$ (66+10 cm row spacing with 13 plants m^{-2} (low density) (Adopted from Zuo et al., 2023)

In Qitai oasis, Xinjiang, a Decision Support System for Irrigation Scheduling (DSSIS) was adopted to help scientifically arrange irrigation time. The system combines precipitation prediction and crop water stress index to optimize water use efficiency. Compared with the method relying on soil moisture sensor, the cotton yield increased by 32% and the water use efficiency increased by 20% after using DSSIS. Under the condition of complete irrigation, the system brings the highest yield and maximum benefit, showing its application value in planting in arid areas (Chen et al., 2020).

6.2 Case 2: planting practice in other arid areas

In order to improve the water use efficiency of cotton in an extremely arid oasis in Northwest China, researchers conducted a two-year experiment. The experiment compared four irrigation strategies, and the results showed that: controlling the irrigation amount to 80% of the field capacity, while saving about 20% of water resources, only 13% of the yield was reduced, which was an ideal scheme for both yield and water saving (Shareef et al., 2018).

In the high-altitude plains of the United States, researchers investigated how different management strategies affect dryland cotton yields through simulation studies. Their findings revealed that early planting and reduced plant density significantly boosted production. The optimal combination of May 15 sowing and a planting density of 3 plants per meter demonstrated the best yield performance in simulations. This indicates that under semi-arid conditions, adjusting sowing timing and planting density can effectively enhance yields while reducing cultivation risks (Mauget et al., 2020).

6.3 Experience summary

Two cases in Xinjiang emphasize the importance of precision irrigation. Shihezi achieved maximum yield by optimizing row spacing and drip irrigation; Qitai improved the yield and water use efficiency with the help of irrigation scheduling system (Chen et al., 2020; Zuo et al., 2023). In areas with water shortage, reasonable irrigation management can effectively improve cotton output.

In contrast, the research in Northwest China proposed water-saving irrigation scheme, which can achieve good benefits even at a slight sacrifice of production; The simulation study in the south of the United States pointed out that proper early sowing and reduction of density could cope with drought risk and improve yield (Shareef et al., 2018; Mauget et al., 2020). Under different climatic conditions, it is necessary to adjust water management and planting methods according to local conditions in order to realize the sustainable development of cotton planting.

7 Economic and Social Aspects

7.1 Economic feasibility of high yield cultivation practice

The economic benefit of developing high-yield cotton planting in arid areas is not single, but also depends on the technology used. For example, cotton and mung bean intercropping (CMBI) is more cost-effective than traditional monoculture. It not only improves the yield per unit of land, but also enhances the ability of crops to absorb nitrogen. Water use efficiency and nitrogen use efficiency also increase, eventually bringing better income (Liang et al., 2020).

The combination of drip irrigation and mulching film can increase the yield and reduce the labor input, so as to improve the net profit (Feng et al., 2017). However, whether these methods are cost-effective depends on whether the local water resources are sufficient. If the water shortage is serious and there is no good irrigation system, drip irrigation will not necessarily make money (Khor and Feike, 2017).

Adjusting irrigation methods can also affect costs and benefits. Under irrigation with field capacity controlled at about 80% can save water and maintain good yield and income (Shareef et al., 2018). Using the treated wastewater to irrigate cotton can not only increase production, but also use less chemical fertilizer, which is also more economically advantageous (De Araújo et al., 2022).

7.2 Labor force and social impact

The high-yield planting mode in arid areas has changed the original labor use structure. Mechanization and precision seeding technology have greatly reduced the labor demand, and cotton planting has become more labor-saving and efficient (Feng et al., 2017). Although the labor cost has been reduced and the burden of farmers has been lightened, the premise is that they have to learn to operate these new equipment. Therefore, training should be carried out to teach them to use agricultural machinery and precision seeding equipment.

Drip irrigation and plastic film mulching, these new irrigation technologies, also require high skills of operators. Systematic training can help farmers allocate water resources reasonably and increase production (Iqbal et al., 2021). If the treated wastewater is used for irrigation, special attention should be paid to the use method to ensure safety and effectiveness (De Araújo et al., 2022).

7.3 Market access and Sustainability

Whether the high-yield cotton planted in arid areas can be sold smoothly is also crucial. A common problem is that the poor quality of cotton fiber, coupled with the pollution of film residue, may be rejected by the market (Feng et al., 2017). In order to enhance competitiveness, we must adopt environmentally friendly planting methods to improve the quality of cotton.

Ecological certification is a breakthrough. If cotton can get the organic or fair trade label, it will be easier to attract consumers who pay attention to environmental protection. Water saving technologies such as under irrigation and reuse of wastewater help to achieve environmental standards and improve the pass rate of certification (De Araújo et al., 2022; Chen et al., 2023). Mulching technology can also conserve water and reduce fertilization frequency, which is also a support for sustainable agriculture (Iqbal et al., 2021).

8 Conclusion

There were significant differences in drought resistance and water use among different cotton varieties. 'tamcot cd3h 'and' tx-cabucs-2-1-83 'are two varieties with high yield and good adaptability in water shortage environment. Irrigation strategy has a great impact on yield. Controlling irrigation at 80% of the field capacity can not only save water, but also maintain a relatively high yield. This method is especially suitable for areas with limited water resources. Irrigation time cannot be arranged at will. Watering at night and controlling the water temperature between 25 ℃ and 28 ℃ will help to improve the photosynthetic efficiency of cotton.

In water-scarce areas, irrigation with treated wastewater is a practical approach. It not only increases yields but also reduces fertilizer use and lowers planting costs. In addition to water management, partial root zone drought and cover treatments (such as laying wheat straw) have also been shown to be effective in saving water, increasing yields and improving cotton quality.

There are several ways to improve cotton yield in arid areas: first, give priority to breeding drought resistant varieties, such as' tamcot cd3h 'and' tx-cabucs-2-1-83 '; Second, adopt reasonable irrigation methods to control the amount and time of irrigation, especially at night and control the water temperature; Third, the proper use of treated wastewater as a source of water is both environmentally friendly and practical; Fourth, covering part of the ground in the field, combined with drought management in part of the root zone, is conducive to water conservation and cotton growth.

These measures have practical significance for cotton production in arid areas. Through scientific seed selection, irrigation and water-saving treatment, farmers can reduce water pressure and improve output. These methods provide a feasible scheme for cotton planting in arid areas, and help to improve crop stability and ensure agricultural development.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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