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RESEARCH ARTICLE

Optimization of cotton irrigation management for different climatic conditions using the CROPGRO-Cotton model

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ABSTRACT

To study the feasibility of CROPGRO_cotton model in the optimization of cotton irrigation management under different climatic conditions, the empirical values corresponding to 25%, 50% and 75% of the empirical frequencies of precipitation were obtained by ranking the frequency fitness line of precipitation data during 20 years of cotton fertility at the experimental site, and then the years corresponding to three empirical frequencies were selected as typical years: 2015 (abundant water year), 2001 (flat water year), and 2006 (dry water year). By combining cotton fertility stages, irrigation frequency and irrigation amount, 21 irrigation regimes (T1～T21) were identified and simulated using the calibrated DSSAT model for cotton irrigation regimes under the three precipitation year types, and the results showed that under the best combination of irrigation usage, yield and water utilization, 2015 (abundant water year), 2001 (flat water year), and T20 irrigation management should be selected in 2006 (dry water year).Under the three typical years, the effect of temperature change on cotton yield and water utilization was investigated, and it was found that the increase of temperature would reduce cotton yield and water utilization, but a reasonable irrigation management would reduce the negative effect of climate change on cotton yield and water utilization,According to the simulation results under different situations, T20 irrigation management can minimize the yield variation range under temperature change, and has a high water utilization rate, which has good applicability.

Keywords: Cotton; DSSAT model; Irrigation management; Typical years; Applicability

INTRODUCTION

Cotton, as a strategic material in China, has a profound impact on the national economy and agricultural development (Wang Shuguang,2019). In recent years, with the rapid development of society, the area of cotton cultivation in China is gradually decreasing. According to the announcement issued by the National Bureau of Statistics, the area of cotton cultivation has been gradually reduced from 4365.97 thousand hectares in 2010 to 3163.9 thousand hectares in 2020. Therefore, how can the limited region, At present, the key point in the field of cotton planting is to plan the planting mode of cotton correctly so as to increase the yield of cotton. At present, There are three major cotton growing regions in China, namely the Yellow River Cotton region, the Yangtze River cotton region and xinjiang cotton region. This article mainly studies xinjiang cotton area, compared with other cotton areas, it has more abundant natural conditions, easier to grow high-quality cotton. The key factor affecting crop yield is the irrigation management, which needs to be optimized in order to increase cotton yield. In addition, Xinjiang region belongs to the temperate continental climate, with little rainfall and frequent climate change, which has a great impact on the growth of cotton. Therefore, it is very important to explore the effect of climate change on the growth and development of cotton.

Crop model can predict crop yield by inputting climate, soil and field management data into the model, which saves a lot of time and resources compared with previous field experiments. Therefore, an appropriate crop model should be selected when studying irrigation management. Nowadays, EPIC mode (Guo Fuxing et al.,2021 ; Feng Genxiang et al., 2021; Wang Xianzhi, 2021), WOFOST model (Xin Xu et al., 2021; Wu Shangrong et al., 2021; Li Ying et al., 2021), DSSAT mode (Wang P.Y. et al., 2021; Gao Yan, 2021; Fu Jingying et al., 2021) are widely used. DSSAT

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model has made great progress in crop growth simulation evaluation (Xu Chunmeng et al., 2021; LI Bo et al., 2021; Li Changxin, 2021), yield prediction research (Zou Yu-Feng, 2020; Sun Yang Yue, 2020; Xiaopei Tang et al.,2018), climate change impact (Wang Ruifeng,2019;WANG Lan et al., 2019; Tang Zeyi, 2020) and so on.

At present, most of the DSSAT model applications on irrigation managements and yields are in areas with sufficient precipitation, mainly focusing on crops such as wheat and maize, and very few studies have been conducted on cotton in Xinjiang, China. Therefore, in this paper, the DSSAT model is used to optimize the irrigation management for cotton in Xinjiang region under different precipitation year types and to analyze the yield and water utilization of cotton through temperature variation, so as to illustrate the applicability of the optimal irrigation management in various climates and provide theoretical support for reasonable irrigation and effective yield increase of cotton in Xinjiang region in the future.

MATERIALS AND METHODS

CROPGRO_cotton model

The CROPGRO model (Li Bo et al., 2020; Cui Jintao et al.,2020; Pan Hui, 2017) is embedded in the DSSAT model, and this family of models contains many crop models, such as rice, soybean, and cotton. The construction of these crop sub-models is basically the same, and the main modules are meteorological parameters, soil parameters and field management modules. The main meteorological parameters are: daily solar radiation, daily temperature, wind speed, rainfall, barometric pressure, etc. Soil parameters are: basic soil composition, soil temperature, soil organic matter content, etc. The field management module is mainly in charge of various management methods, such as cultivation date, cultivation method, irrigation, fertilization, harvesting, etc. There are three main categories of parameters for CROPGRO model to simulate crop growth and yield: variety parameters, ecological parameters, and species parameters.

Overview of the test site

Cotton was sown in April and harvested in October at the trial site, which is located in Alar, South Xinjiang, China (81°.58'E, 40°.57'N). The average altitude of the test site is 1011m, the air pressure is 90KPa, the annual sunshine is about 2788h, the annual solar radiation is about 133cm2, the annual average temperature is about 11.4°, the annual average rainfall is 50mm, the rainfall is small, the inter- and intra-annual variation is relatively large, the annual average evaporation is 2558mm, which is about 40 times of the rainfall. The soil composition of the test site is mainly sandy loam, sub-clay and sandy soils, which are relatively fertile and particularly suitable for crop growth.

Model input parameters and data sources

The input parameters of the model are mainly the crop variety parameters of cotton, variety parameters are mainly in charge of the crop variety genetics, growth and development, yield traits, the calibration of the model is usually to correct the crop variety parameters, the variety parameters of cotton are shown in Table 1. the field management data required for the model are from the test site observations, the soil data are from the soil sampling survey of the test site at different depths, the soil data of the test site are shown in Table 2.

The weather data were obtained from the China Meteorological Data Network, however, due to the lack of local meteorological data in Alar, Xinjiang, the typical year was selected by ranking the frequency of the appropriate line of precipitation data during the fertility period of cotton in the test site from 2001 to 2020, and obtaining the empirical frequency of precipitation corresponding to 25%, 50%, and 75%, respectively, from which the corresponding representative year was selected.

Extended fourier test

The extended Fourier test is a sensitivity analysis method based on variance decomposition.EFAST is the use of the

Table 1: Cotton variety parameters

Parameters	Description	Unit
CSDL	Critical photoperiod	h
PPSEN	Photoperiodic sensitivity factor	-
EM-FL	Light and heat time from seedling emergence to first flowering	pdt
FL-SH	Photothermal time from first flowering to first boll production	pdt
FL-SD	Photothermal time from first flowering to first seed production	pdt
SD-PM	Photothermal time from first seed production to physiological maturity	pdt
FL-LF	Photothermal time from first flowering to cessation of leaf expansion	pdt
LFMAX	Maximum photosynthetic rate of leaves under optimum conditions	$mgCO_2/m^2s$
SLAVR	Specific leaf area	cm^2/g
SIZIF	Single leaf area	cm^2
XFRT	Maximum percentage of dry matter mass allocated to cotton boll per day	%
WTPSD	Maximum seed weight	g
SFDUR	Duration of seed-filled boll bins	pdt
SDPDV	Average number of seeds per cotton boll under normal conditions	#/pod
PODUR	Time required for final boll loading under optimal conditions	pdt
THRSH	Ratio of seed cotton mass to boll mass	%
SDPRO	Protein content in the seeds	g/g
SDLIP	Content of oil in the seeds	g/g

Table 2: Soil data

Depth (cm)	Soil nitrate nitrogen (mg/kg)	Soil ammonium nitrogen (mg/kg)	Soil alkaline decomposition nitrogen (mg/kg)	Soil fast-acting phosphorus (mg/kg)	Soil fast-acting potassium (mg/kg)	Soil organic matter (%)
0~20cm	197.28	4.65	23.51	23.29	95.38	0.44
20~40cm	67.01	4.36	12.83	4.54	90.07	0.35
40~60cm	83.59	4.74	13.6	4.2	96.54	0.34
60~80cm	80.24	5.02	9.78	4.96	105.86	0.25

Fourier transform to obtain the spectral curve of the Fourier series, followed by the use of this curve to obtain the variance of the model due to the interaction between all parameters and participation, which is calculated by the formula

$$V(Y) = \Sigma_{i=1}^{n} V_i + \Sigma_{ij\leq}^{n} V_{ij} + \ldots + V(1,2,\ldots,n) \quad (1)$$

$$V_{ij} = V[E(Y \mid x_i x_j)] - V_i - V_j \quad (2)$$

$$S_i = \frac{V_i}{V(Y)} \quad (3)$$

$$S_{\tau i} = \frac{V(Y) - V_{-i}}{V(Y)} \quad (4)$$

In the formula: V_{ij} is the variance of the interaction of the variables; is the sum of variances after removing variable; V_{-i} is the first-order sensitivity index of variable x_i, $S_{\tau i}$ is the global sensitivity index of variable x_i

Research Methodology

Using a combination of DSSAT model parameter sensitivity analysis, model calibration and validation, irrigation management optimization, and applicability evaluation, field management, soil, and meteorological data were entered into the DSSAT model, sensitivity parameters were determined by parameter sensitivity analysis, and then cotton variety parameters were calibrated using the GLUE+ trial-and-error method until the error between the actual measured and model simulated values was qualified. The degree of error between the measured and simulated values was measured using the relative error ARE. It is generally considered that the simulation results are excellent when ARE ≤ 10%, good when 10% ≤ ARE ≤ 20%, moderate when 20% ≤ ARE ≤ 30%, and poor when ARE ≥ 30%.

Jiu-Gang Yang (YANG Jiugang et al., 2011) et al. implemented four irrigation amount and 12 irrigation frequencies to study the growth and yield of cotton under film drip irrigation in South Xinjiang, and the analysis showed that 12-16 irrigation times and 375-450 mm irrigation amount were the best irrigation for sandy loam soil in South Xinjiang. In this paper, the irrigation management was optimized by the specific situation of cotton irrigation at the bud and boll stage in the test site, combined with the characteristics of low precipitation in the area, and the seedling and flocculation stages of cotton were added in the simulated irrigation. In addition, according to the document "Irrigation amount in Xinjiang province" published by Xinjiang provincial water resources department, the irrigation amount for cotton in the western margin of Tarim basin in southern Xinjiang is 6450 m^3/hm^2 when the empirical frequency of precipitation is 75%, and to ensure the yield of cotton, the maximum irrigation amount is 520 mm and 21 irrigation methods are set in this paper, see Table 3. The optimal irrigation management was selected by three indicators: irrigation amount, cotton unit yield, and water utilization rate. The water use efficiency (WUE) was calculated as:

$$WUE = \frac{Y}{10ET}$$

In the formula: WUE is water utilization efficiency,Kg/m^3;Y is the yield,kg/hm^2;ET is evapotranspiration,mm.

The irrigation amount is divided into: 18mm, 24mm, 30mm, 36mm, 40mm.

In order to adapt to climate change in Xinjiang, by analyzing the temperature changes in the past 20 years, the study found that the average temperature in Xinjiang is increasing at a uniform rate of 0.3°C per decade, and this large degree of temperature change will affect the growth and development and yield of cotton, so the applicability of the optimal irrigation management under future climatic conditions needs to be studied.

RESULTS AND ANALYSIS

Sensitivity analysis of crop model parameters

Sensitivity of breed parameters to flowering time

As can be seen from Fig. 1, among the 18 variety parameters in the CROPGRO_cotton model, the only parameter that

Table 3: Irrigation management treatments

Irrigation management	Irrigation amount at seedling stage	Irrigation amount during the budding period	Pre-bell irrigation amount	Late flower bell irrigation	Irrigation amount during the flocculation period	Total irrigation amount
T1	0	0	0	0	0	0
T2	0	54	54	90	0	198
T3	0	72	72	120	0	264
T4	0	90	90	150	0	330
T5	0	108	108	180	0	396
T6	0	120	120	200	0	440
T7	18	54	54	90	0	216
T8	24	72	72	120	0	288
T9	30	90	90	150	0	360
T10	36	108	108	180	0	432
T11	40	120	120	200	0	480
T12	18	54	54	90	18	234
T13	24	72	72	120	24	312
T14	30	90	90	150	30	390
T15	36	108	108	180	36	468
T16	40	120	120	200	40	520
T17	0	54	54	90	18	216
T18	0	72	72	120	24	288
T19	0	90	90	150	30	360
T20	0	108	108	180	36	432
T21	0	120	120	200	40	480

T1 was rainfed. The actual conditions of the test site set the irrigation time as follows: seedling stage (May 27); bud stage (June 7, June 17, June 23); pre-bell stage (July 3, July 10, July 14); late bell stage (July 25, July 31, August 6, August 13, August 20); and flocculation stage (August 28)
The irrigation amount is divided into: 18mm, 24mm, 30mm, 36mm, 40mm
Irrigation frequency: every 6~11 days

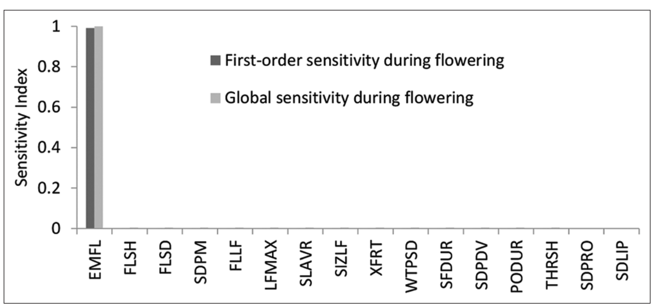

Fig 1. Sensitivity index of varietal parameters to flowering period.

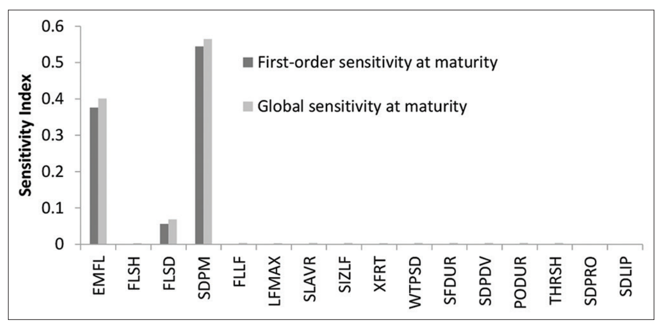

Fig 2. Sensitivity index of varietal parameters to maturity.

is sensitive to the flowering period is EF-FL (light and heat time from emergence to first flowering), which corresponds to a first-order sensitivity index and a global sensitivity index of 0.99. The reason for this is mainly that temperature determines the early and late flowering of cotton.

Sensitivity of breed parameters to maturity

As can be seen from Fig. 2, among the 18 varietal parameters sensitive to maturity in the CROPGRO_cotton model, EF-FL (photothermal time from seedling emergence to first flowering) and SD-PM (photothermal time from first seed production to physiological maturity), their corresponding first-order sensitivity indices are 0.38 and 0.55, respectively, and their corresponding global sensitivity indices are 0.4 and 0.56.

Sensitivity of varietal parameters to yield

As can be seen from Fig. 3, among the 18 varietal parameters in the CROPGRO_cotton model that are sensitive to the flowering period are EF-FL (light and heat time from emergence to first flowering) and XFRT (maximum proportion of dry matter mass allocated to cotton boll per day), which correspond to first-order sensitivity indices of 0.22 and 0.59, respectively, and to global sensitivity indices of 0.28 and 0.61.

Sensitivity of species parameters to biomass

As can be seen from Fig. 4, among the 18 varietal parameters in the CROPGRO_cotton model that are sensitive to the flowering period are EF-FL (light and heat time from emergence to first flowering) and SDPM (maximum proportion of dry matter mass allocated to cotton boll per day), which correspond to first-order sensitivity indices of 0.22 and 0.26, respectively, and to global sensitivity indices of 0.61 and 0.65.FL-SD (photothermal time from first flowering to first seed production) and LFMAX (leaf maximum photosynthetic rate under optimum conditions) changed from non-sensitive to sensitive parameters due to the interaction between parameters, and they corresponded to global sensitivity indices of 0.22 and 0.11, respectively.

Correction of parameters and validation of the model

The sensitivity parameters analyzed in the previous section were corrected by the GLUE procedure that comes with the DSSAT model and combined with the trial-and-error method, and the results of the parameter correction are shown in Table 4.

The comparison between simulated and measured values of flowering, maturity, yield and biomass of cotton in 2017 and 2018 is shown in Table 5.

As can be seen from Table 5, the simulation results of the model on the model calibration treatment basically matched with the measured values, in which the mean ARE values of flowering stage, maturity stage, yield, and biomass simulation and measured values were 4.8%, 5.7%, and 8.8%, respectively. For the validation treatments, the simulated and measured values of flowering and maturity were in basic agreement, and the error of yield was large under the T1 treatment (T1 was a low irrigation treatment),

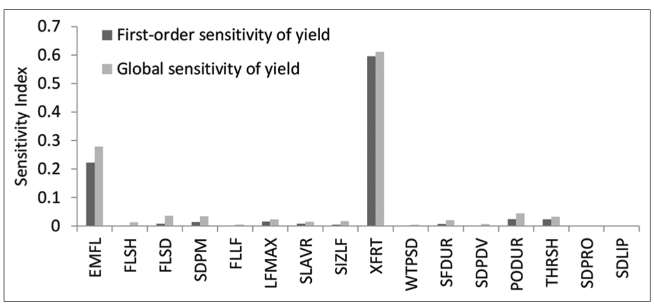

Fig 3. Sensitivity index of varietal parameters on yield.

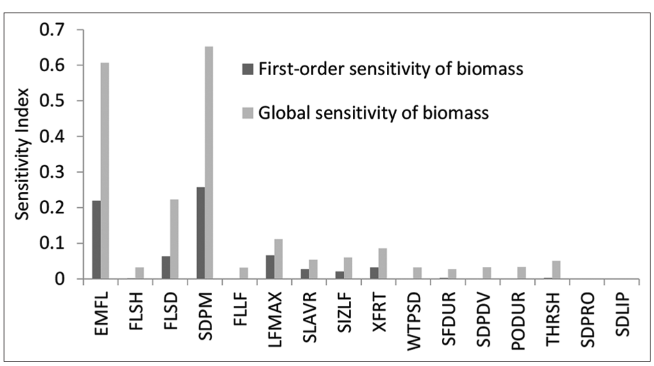

Fig 4. Sensitivity of biomass to cultivar parameters.

so the model could simulate well the situation of sufficient water, and for the water stress treatment, there would be some error between the simulated and measured values. Comparing yield and phenological stage, the simulation results of biomass are poor, which may be due to the fact that cotton in Xinjiang needs topping, and the DSSAT model lacks functions such as topping and whole branching, resulting in poor simulation results of biomass.

Select a representative year

Through the test site in 20 years of cotton fertility rainfall data for the row of frequency appropriate line, to obtain the empirical value of the empirical frequency of precipitation for 25%, 50%, 75% corresponding to 103.87mm, 81.01mm, 35.07mm, respectively, and then select the year corresponding to the three precipitation frequency as a typical representative year (abundant water year 2015, flat water year 2001, dry water year 2006), as shown in Fig. 5 (E_X=95, C_V=0.86, C_S=2CV in the figure).

Optimal irrigation management under different precipitation year patterns

The growth and development of cotton under each irrigation management in three typical years were simulated by the calibrated DSSAT model, and the optimal irrigation management was selected by considering the three elements of irrigation use, cotton yield, and WUE. As can be seen from Table 6, cotton WUE was highest in 2015 (abundant water year) under irrigation regime T21 with 0.866 kg/m^3, and cotton yield and WUE were higher in irrigation regimes T6 and T20 with 5304 kg/hm^2, 0.865 kg/m^3 and 5017 kg/hm2, 0.847 kg/m^3, respectively. 2001 (flat water year), cotton WUE under irrigation management T20 was the highest at 0.954kg/m^3, while cotton yield and WUE under irrigation managements T15 and T6 were higher at 5603kg/hm^2, 0.912kg/m^3 and 5248kg/hm^2, 0.884kg/m^3,

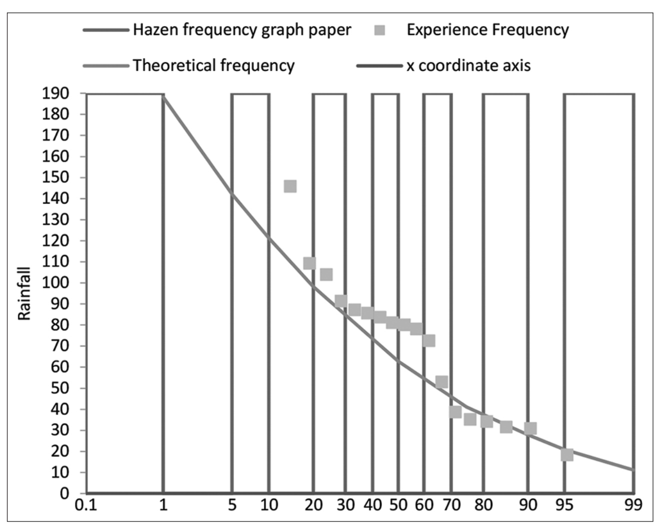

Fig 5. Rainfall discharge frequency fitness line diagram.

Table 4: Calibration results of cotton variety parameters

Parameters	Description	Unit	Correction value
EM-FL	Light and heat time from seedling emergence to first flowering	pdt	42.7
SD-PM	Photothermal time from first seed production to physiological maturity	pdt	39.9
LFMAX	Maximum photosynthetic rate of leaves under optimum conditions	$mgCO_2/m^2s$	1.44

Table 5: Calibration and validation results of the model

Year	Treatments	Flowering period			Maturity period			Yield			Biomass		
		Sim	Obs	ARE	Sim	Obs	ARE	Sim	Obs	ARE	Sim	Obs	ARE
2017 Model Calibration	T1	87	83	4.8%	181	195	7.1%	4885	5645	13.4%	11701	12528	6.6%
	T2	87	83	4.8%	183	195	6.1%	5995	6637	9.6%	14651	16371	10.5%
	T3	87	83	4.8%	187	195	4.1%	6247	6026	3.6%	17208	15803	8.8%
Average error				4.8%			5.7%			8.8%			8.6%
2018 Model Validation	T1	81	82	1.2%	173	188	7.9%	3345	4690	28.6%	10602	15878	33.2%
	T2	81	82	1.2%	177	188	5.8%	5166	5124	0.8%	13471	17122	21.3%
	T3	81	82	1.2%	180	188	4.2%	6220	5655	9.9%	16186	18876	14.2%
Average error				1.2%			5.9%			13.1%			22.9%

ARE is the relative error,%; Sim and Obs are the simulated and observed values, respectively

Table 6: Simulation results of cotton yield and water utilization under different precipitation year types

irrigation management	2015 (abundant water year)		2001 (flat water year)		2006 (dry water year)	
	$Y/(kg{\cdot}hm^{-2})$	$WUE/(kg{\cdot}m^{-3})$	$Y/(kg{\cdot}hm^{-2})$	$WUE/(kg{\cdot}m^{-3})$	$Y/(kg{\cdot}hm^{-2})$	$WUE/(kg{\cdot}m^{-3})$
T1	294	0.171	367	0.229	409	0.272
T2	1035	0.274	1165	0.323	1141	0.326
T3	1883	0.423	2019	0.475	2318	0.559
T4	3044	0.589	3498	0.713	3560	0.743
T5	4758	0.821	4842	0.877	4679	0.863
T6	5304	0.865	5248	0.884	5774	0.991
T7	1027	0.260	1195	0.316	1160	0.315
T8	1947	0.413	2137	0.476	2404	0.549
T9	3100	0.569	3610	0.696	3655	0.721
T10	4771	0.782	4899	0.841	4906	0.858
T11	5445	0.847	5472	0.877	6080	0.996
T12	1400	0.338	1552	0.392	1478	0.384
T13	2651	0.537	2847	0.603	2893	0.628
T14	3877	0.678	4602	0.842	4286	0.802
T15	5012	0.804	5603	0.912	5996	0.992
T16	5445	0.847	5628	0.867	6635	1.040
T17	1403	0.354	1512	0.400	1456	0.397
T18	2665	0.566	2720	0.606	2813	0.644
T19	3872	0.711	4496	0.867	4198	0.828
T20	5017	0.847	5577	0.954	5781	1.005
T21	5305	0.866	5453	0.878	6591	1.075

respectively. 2006 (dry water year) cotton WUE under irrigation management T21 was was the highest at 1.075 kg/m3 and cotton yield and WUE were higher under irrigation managements T16 and T20 at 6635 kg/hm2, 1.04 kg/m3 and 5781 kg/hm2, 1.005 kg/m3, respectively.

Considering the 3 elements of irrigation use, cotton yield, and WUE, T20 should be selected for the irrigation management in 2015 (abundant water year), 2001 (flat water year), and 2006 (dry water year).

Impacts on crops under climate change and applicability of optimal irrigation

Ding Yihui (Ding Yihui et al.,2007) et al. showed that the increase in surface temperature in China is 0.5°C~0.8°C, which is much higher than the rate of temperature increase in the Northern Hemisphere during the same period, and indicated that the frequency of extreme climate events in China is significantly increasing, and extreme climate events can have certain impacts on different industries, especially regional droughts caused by climate change may lead to serious challenges for China's agricultural development. Therefore, in order to adapt to climate change in Xinjiang, by analyzing the temperature changes over the past 20 years (Fig. 6), the study found that the average temperature in Xinjiang is increasing at a uniform rate of 0.3°C per decade, and this large degree of temperature change can affect the growth and yield of cotton, so the applicability of irrigation managements under future climatic conditions needs to be studied.Twelve climate change scenarios were generated based on three typical years selected at the experimental site (Table 7), and cotton yield, irrigation amount and WUE under irrigation managements T1 to T21 were simulated by the DSSAT model under 12 climate changes. The study showed (Fig. 7) that when the temperature increased by 0.5, 1, 1.5, and 2°C, the yield decreased on average -251, -449, -713, and -994 kg/hm^2 under 21 irrigation managements for each scenario, which indicates that cotton yield decreases with the increase in temperature. The simulated mean values of yield under irrigation managements from T1 to T21 under different climate changes were 315, 925, 1750, 2838, 4048, 4554, 928, 1808, 2876, 4056, 4620, 1163, 2289, 3452, 4579, 4880, 1162, 2227, 3442, 4788, and 4838 kg/hm^2, comparing the mean values of yield changes under no change climate were -42, -189, -323, -529, -712, -888, -199, -355, -579, -803, -1046, -314, -508, -803, -958, -1023, -295, -506, -747, -670, -945kg/hm^2. This shows that the T20 irrigation management can minimize the yield variation under 12 climate changes considering the yield and irrigation amount, which indicates that the increase in temperature will adversely affect the cotton yield, but a reasonable irrigation management will reduce the adverse effect of climate change on yield.

Climate change not only affects cotton yields, but also affects the water utilization of cotton.From Fig. 8, it can be seen that the average decrease in WUE for 12 climate change scenarios compared to the no change scenario under T1 to T21 irrigation regimes is 0.024, 0.05, 0.073, 0.101, 0.12, 0.143, 0.05, 0.075, 0.105, 0.13, 0.163, 0.076, 0.1, 0.137, 0.147, 0.153, 0.074, 0.104, 0.133, 0.138, 0.142 kg/m^3, and the average decrease in WUE for each 0.5°C increase in temperature was 0.106 kg/m^3 for the 21 irrigation regimes.Among them, WUE was highest under T21 irrigation management, and removing rainfed conditions, WUE was lowest under T7 irrigation management, and water utilization was higher under T20 and T6 irrigation managements. Therefore, considering the effects of different climate changes on cotton yield and water utilization, T20 irrigation management still has better applicability.

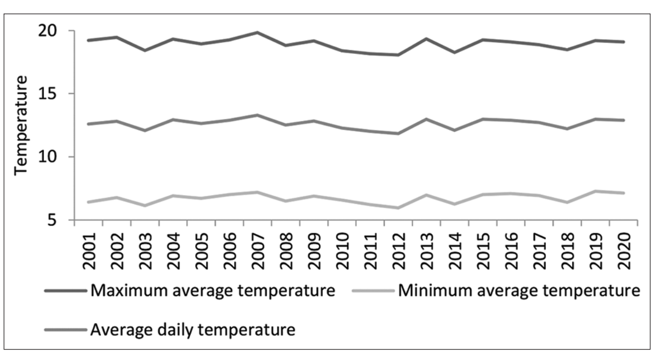

Fig 6. 20-year temperature change graph.

DISCUSSION

In this paper, we simulated the water utilization rate of cotton under different irrigation managements, and the study found that all water utilization rates were low because of the lack of some day-by-day weather data in this paper, so this paper chose the priestley-taylor formula for the total evapotranspiration loss of soil water in the DSSAT model, while previous studies chose the FAO-56 formula (Ouaadi Nadia et al., 2021), which led to the ET (evapotranspiration) calculation is not accurate enough, which in turn causes low water utilization calculation.

In this paper, we simulated cotton yields under different irrigation managements and showed that the yields in the dry water year were higher than those in the abundant water year when comparing the same irrigation management, and the reasons for this situation are multiple. First, the

Table 7: Different climate change scenarios under a typical year

Precipitation year type	Climate change scenarios	Definition
abundant water year	+0.5°C	Temperature increase by 0.5°C
	+1°C	Temperature increase by 1°C
	+1.5°C	Temperature increase by 1.5°C
	+2°C	Temperature increase by 2°C
flat water year	+0.5°C	Temperature increase by 0.5°C
	+1°C	Temperature increase by 1°C
	+1.5°C	Temperature increase by 1.5°C
	+2°C	Temperature increase by 2°C
dry water year	+0.5°C	Temperature increase by 0.5°C
	+1°C	Temperature increase by 1°C
	+1.5°C	Temperature increase by 1.5°C
	+2°C	Temperature increase by 2°C

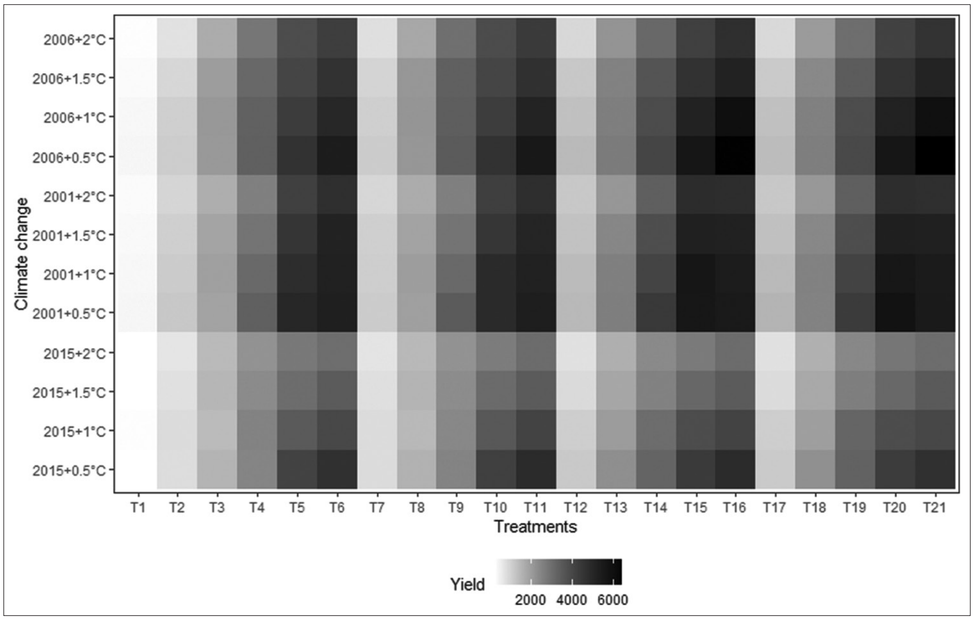

Fig 7. Simulated values of cotton yield under different irrigation managements in the experimental site under different climate changes.

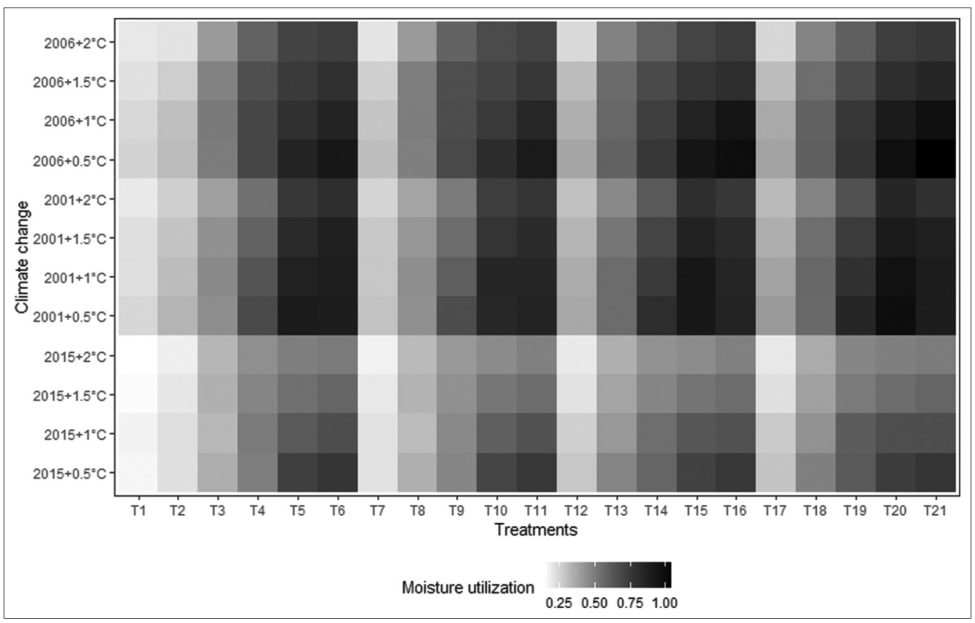

Fig 8. Simulated values of water utilization under different irrigation managements for cotton in the experimental site under different climate changes.

measured values of yield and precipitation for 20 years during the cotton reproductive period in the test site showed that the two did not exactly show a positive correlation, and the representative years chosen were only three typical examples, so the simulation results may show a low yield in the abundant water year. Secondly, the rainfall in the abundant water year would be higher and the deep soil of the test site would be mostly sub-clay with poor permeability, which would easily cause saturation, and saturation would lead to a lack of oxygen in the root zone of cotton, reduced root vigor, inhibited growth and development, and thus reduced yield. These two reasons may jointly cause the above simulation results. Although the simulation results of the model have some errors, the errors are within a certain degree, which still have some guiding significance for the optimization of irrigation management in South Xinjiang region.

Since the growth and development of cotton is affected by many factors, such as rainfall, light and temperature, the effect of changes in temperature on cotton yield and water utilization when the irrigation management and precipitation conditions are the same is investigated next,However, the optimal irrigation management for cotton under different climates studied in this paper only represents most of the specific years and specific irrigation managements, and its role is mainly to provide some ideas for local cotton irrigation managements, and further optimization of irrigation managements can be implemented in the future in combination with the initial soil water content.

The DSSAT-CROPGRO-Cotton model used in this paper lacks functions such as topping and grooming at the same time it does not take into account the effect of soil salinity on cotton growth and development and yield, and soil salinization is common in Xinjiang, so soil salinity, weather, pests and diseases should be taken into account in future studies to make more detailed analysis for future model studies and irrigation methods.

CONCLUSIONS

(1) After parameter sensitivity analysis, the DSSAT model was used to correct for crop variety participation, and the model simulated better flowering, maturity, yield, and biomass, and the corrected model was more reliable.

(2) By combining the cotton fertility stages and the number of irrigation and irrigation amount, 21 irrigation managements (T1~T21) were identified, and under the comprehensive consideration of optimal irrigation use, yield and water utilization, T20 irrigation management should be selected in 2015 (abundant water year), 2001 (flat water year) and 2006 (dry water year).

(3) The effects of different climate changes on cotton and the applicability of optimal irrigation were found that the increase in temperature would lead to a decrease in cotton yield and water utilization, but a reasonable irrigation management would reduce this adverse effect, and according to the simulation results under different scenarios, the T20 irrigation management could reduce the adverse effects of climate change relatively well and had good applicability.

(4) This study shows that an additional once irrigation during the cotton spatting period in southern Xinjiang, China, can increase cotton yield and water use efficiency to a small extent and reduce water wastage.

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