Advances in the Study of Aquacrop Crop Models

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Abstract

Based on crop physiology and growth process, the long model simulates the dynamic growth process of crops according to meteorological conditions, soil characteristics and crop management measures, analyzes the relevant influence factors, and optimizes the planting mode to provide suitable ones. As one of the most widely used models in many crop models, Aquacrop is mainly expounded for the development process, theoretical basis, main modules and application fields of the model, and by analyzing the representative results of the model in the simulated regional productivity at home and abroad, this paper summarizes and discusses the model in exploring suitable irrigation system, optimizing the design of crop varieties and improving the water efficiency of crops and embodying them in crop yield, providing theoretical basis and scientific guidance for experiments.

Keywords

Crop Model; Aquacrop; Model Application; Productivity Forecasts.

1. Introduction

Cotton industry is the leading agricultural industry in Xinjiang. Xinjiang's cotton output has accounted for 67% of the national output, and it is the largest cotton producing area and commercial cotton base in China [1]. During the development of Xinjiang's cotton industry, drip irrigation under film cultivation technology has played a huge role[2]. At present, the film covering rate of Xinjiang's cotton has reached 100%[3]. However, as time goes by, the disadvantages of this cultivation mode gradually show up. The used mulch film is often difficult to recover completely. It is preliminarily estimated that the residual amount of mulch film in farmland has reached 158.4 kg/hm^2[4]. The residual film not only affects the growth of cotton, but also seriously threatens the sustainable development of regional agriculture[5]. For the control and recovery of residual film, there are many technologies at present, such as electrostatic recovery device for residual film[6], roller type residual film recovery machine[7], etc. But due to low recovery efficiency, different thickness of mulch film, weak awareness of farmers to recover residual film and other reasons [8], the recovery effect of mulch film is not ideal. With the trial planting and popularization of Chinese cotton "619" in Aksu area of southern Xinjiang, a new solution to the problem of residual film is provided. Due to the difference of soil environment and soil temperature accumulation between film free planting and film covered planting, it is necessary to study management measures for film free cotton planting.

Field test is a common method for crop growth research. However, due to different soil conditions, environmental climate, etc. In different regions, it often requires a large number of cross test results on crop varieties, meteorological conditions, field management, etc. to explore the biological growth and production mechanism[9], and the field test is low in efficiency because of its high cost, long test cycle, and vulnerability to diseases, insects and other natural disasters[10]. Therefore, the crop model based on the farmland SPAC (soil plant atmosphere continuum) system has become a research hotspot of scholars at home and abroad due to its advantages such as short test cycle, high simulation

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accuracy, and reduction of crop yield loss due to regional climate change[11], and has become an important means of agricultural research[12].

Since the 1960s, various countries have developed a variety of crop models, which can be roughly divided into three types. One is the light driven type, which drives crop photosynthesis through light to form crop yield, such as the CERES series models in the United States; The second is the CO_2 driving type, which drives crop growth through CO_2 assimilation and light interception, such as the Dutch WOFOST model; The third is the water driven model, which affects crop yield by controlling available soil water, such as the Aquacrop model launched by FAO.

Crop models also have many shortcomings, mainly including the following: ①Many crop models have incomplete core driving parameters, which can not comprehensively simulate the impact of limiting factors on crop production; ②The operation of various models is complex and professional, which leads to great difficulty in using models, high requirements for model users[13], and small scope of use; ③Influenced by the model developer, the driving mechanism of crop model adopts a large number of time and regional parameters, which makes its application scope limited.

Based on the above aspects, the World Food and Agriculture Organization (FAO) organized experts from various countries and fields to jointly develop a water driven model - Aquacrop model in 2009[14-15].

2. Aquacrop Model Overview and Principle

2.1 Introduction to the Model

Aquacrop model focuses on the response mechanism of crops to water at the micro level. Through the simulation of the soil crop atmosphere system, the impact of human factors and natural factors in the crop growth process is fully considered, and the soil evaporation and crop transpiration are carefully separated, thus effectively improving the accuracy of simulation; For the first time, the change of canopy coverage was used to replace the increase or decrease of leaf area index in other models, which successfully avoided the influence of other uncertain factors on the simulation results in the growth stage of crops; The model is mainly divided into air module, crop module, field management module and soil module. Because it has the advantages of few input parameters, simple operation, low cost, etc., and has greatly optimized the accuracy of simulation, stability of performance and simplicity of structure, it can be used as a tool to study crop productivity level and risk assessment, cultivation technology decision-making, etc[16-20]. Since its release, it has rapidly gained the favor of scholars and researchers at home and abroad, and has become a hot spot of current research. At present, its research results have been applied to various countries in the world.

2.2 Theoretical Basis of Model

(1) Crop transpiration

The model divides crop evapotranspiration into two parts: soil evaporation (E) and crop transpiration (Tr) to avoid confusing the impact of non-production water (soil evaporation) and production water (crop transpiration) on crop water demand; The final yield is expressed by the product of biomass (B) and harvest index (HI). The biomass is expressed by water production efficiency (WP) and cumulative crop transpiration to distinguish the effects of water deficit on them. The expression is as follows:

$$Y = B \times HI \quad (1)$$

$$B = WP \times \sum Tr \quad (2)$$

Where, Y is the final crop yield ($kg \cdot m^{-2}$), B is the biomass ($kg \cdot m^{-2}$), HI is the crop harvest index (%), Tr is the crop transpiration (mm), and WP is the biomass water production efficiency ($kg \cdot m^{-2} \cdot mm^{-1}$).

(2) Canopy coverage

Generally, canopy coverage (CC) is used to replace the traditional leaf area index (LAI) to describe the growth and development process of crops. Canopy growth at the growth stage of crops is expressed by canopy growth coefficient, and the conversion formula is as follows:

$$CC = CC_0 \times e^{t \times CGC} \tag{3}$$

In the formula, the canopy coverage when CC is t; CC_x is the maximum canopy coverage; CC_0 is the initial canopy coverage (or the canopy coverage when t=0); CGC is the canopy growth coefficient; The unit of t is per day or per birth length day.

3. Main Research Progress

3.1 Domestic Research Status

Since the release of Aquacrop model, domestic researchers have carried out a lot of research on different crops in various regions and made many important achievements.

3.1.1 Research on Aquacrop Model for Winter Wheat by Domestic Scholars

In 2014, Xiuliang Jin et al.[21] calibrated and simulated the model using five years of field winter wheat data in the North China Plain, and found that the canopy coverage, biomass yield and seed cotton yield were consistent with the measured values, suggesting that the model had good simulation accuracy for local winter wheat; M. Anjum Iqbal et al.[22] also found that the significant differences in grain yield, biomass and ET_a of winter wheat simulated and observed by Aquacrop model in the same year were as follows: rain fed treatment > good water treatment > moderate water stress, indicating that the simulation accuracy of the modified model was better under low water stress. With the increase of water stress, the simulation accuracy decreased, but the simulation error of all indicators was within a reasonable range; Zhou Yingxia et al.[23] found through the simulation of this model that the yield of winter wheat will decrease slightly with the increase of temperature, but with the increase of CO_2 concentration, the yield of winter wheat will increase. When temperature and CO_2 concentration increase at the same time, the yield reduction caused by the increase of temperature can be offset by the positive synergy of the two meteorological factors.

3.1.2 Domestic Scholars' Research on Summer Corn based on Aquacrop Model

In 2009, Hsiao et al.[24] adjusted and checked the parameters of the modified model using years of test data, and obtained simulation parameters suitable for corn growth in all regions. Ni Ling et al.[25] adjusted the parameters in the Loess Plateau region in 2015 based on this parameter to obtain model parameters suitable for local field corn growth. At the same time, they found that the simulation effect of the model on summer corn yield was also good due to the simulation of biomass, and the simulation of crop evapotranspiration; Chen Chaofei et al.[26] (2019) used Aquacrop model to study the change characteristics of water use efficiency in various rainfall year types and water use efficiency in Guanzhong area, and found that high yield and water use efficiency can be obtained without irrigation in wet years. In normal water years, it is recommended to irrigate 60 mm at jointing stage, which can save 50% of water resources, providing theoretical support for the optimization of summer maize irrigation system in Guanzhong area;

3.1.3 Domestic Scholars' Research on Aquacrop Model for Other Crops

Shuai Tan et al.[27] simulated the drip irrigation cotton under plastic film affected by saline soil in southern Xinjiang according to the cotton parameters recommended in the Paddy Field Crop Manual, and the results were in good agreement with the field observation results of many years of experiments, which explored the application of Aquacrop model in drip irrigation cotton under plastic film in southern Xinjiang, and provided reference for the optimization of drip irrigation system under plastic film in similar regions; Li Zizhong et al[28]. Qin Zhitong[29] averaged the multi-year average meteorological data during the growth period of spring maize, established a meteorological database, and then simulated and analyzed 16 irrigation systems using Aquacrop model. The recommended optimal irrigation system for spring maize is 70 mm, 60 mm and 75 mm respectively at jointing stage, bellowing stage and tasseling stage. The total irrigation quota is 205 mm, which can achieve stable yield. In the process of using Aquacrop model, domestic scholars also found some shortcomings of the model, and made various corrections. Yang Ning et al[30], Compared with the simulation results before and after modification, it is found that the improved Aquacrop model has better mechanism and applicability for film covered corn; In 2016, Xiuliang Jin et al.[31] combined remote sensing data with the Aquacrop model, calibrated the AquaCrop model using particle swarm optimization algorithm (PSO), and applied it to the winter wheat experiment in Beijing Xiaotangshan Experimental Ground, which achieved good simulation results, providing a new method for model application and agricultural resource management.

3.2 Research Status Abroad

3.2.1 Foreign Scholars' Research on Maize Using Aquacrop Model

Foreign researchers have also carried out a lot of research on model adaptation evaluation. Heng et al.[32] simulated maize production in different regions of the United States. The results show that under full irrigation and light water stress conditions, the AquaCrop model has good consistency in simulating aboveground biomass, water use efficiency and grain yield; In 2014, P. Paredes et al.[33] conducted a field corn experiment with less water and full irrigation in Ribatejo, Portugal. They assessed the impact of water stress on corn yield through Aquacrop model. Through comparison of simulated values with measured values, they found that the modified model often overestimated the evapotranspiration of crops and underestimated the impact of soil evaporation on crops. However, the prediction results of crop biomass and yield were good. The overall results showed that, Under the condition of less water irrigation, the estimation results of water stress on maize biomass and yield are better. When the measured data are not available, the simulation data of the modified model can be used; In 2016, Mohammad Hassanli et al.[34] conducted field corn experiments using saline water and non saline water under different conditions in Karachi, Iran. According to the experimental data, the Aquacrop model, SALTMED model and SWAP model were checked and verified respectively. The results showed that the Aquacrop model was slightly different from the other two models in estimating corn yield under salt stress; Abedin et al.[35] showed that Aquacrop model can predict maize growth, final yield and biomass under different water conditions, and the simulation accuracy is within a reasonable range ($R^2>0.65$), and the simulation accuracy decreases under water stress;

3.2.2 Foreign Scholars' Research on Soybean Using Aquacrop Model

Paredes et al.[36] evaluated the ability of predicting biomass and yield of soybean by Aquacrop model. The results showed that the measured and simulated values of canopy coverage fit well, and the parameterized model has certain applicability for estimating yield and biomass of soybean, but it is not suitable for optimizing irrigation system of soybean.

3.2.3 Foreign Scholars' Research on Aquacrop Model for Other Crops

Dimitrios Voloudakis et al. [37] used the Aquacrop model as a crop growth simulation tool under eight climate models (HadRM3, C4I, REMO-MPI, ETHZ, CNRM, DMI-HIRHAM, KNMI, SMHI). The research predicted the impact of climate change on cotton yield of seven major cultivated land (Agrinio, Alexan Dropoli, Arta, Karditsa, Mikra,Pyrgos, Yki) in Greece from 1961 to 2100. It has certain reference value for future irrigation planning of the research area. Araya et al.[38] showed that the Aquacrop model was reasonable and effective to simulate barley biomass and yield at different seeding dates, and the model could be used to optimize the optimal seeding time, and the simulated results under mild water stress were slightly worse than that under full irrigation. Raphael Linker and others[39] used the Aquacrop model to verify and validate cotton, potato and tomato in 2016, and optimized the model, taking the response of crops to water stress into account, and obtained the expression of the relationship between water quota and yield.

4. Problems and Prospects

At present, the Aquacrop model has been evaluated and verified on the applicability of a variety of crops in various regions, but there are relatively few studies on drip irrigation of cotton without film in southern Xinjiang. Because most of the local cotton is planted with film mulching, and film free planting is only planted in the experimental field, the model needs to be scientifically studied to develop a reasonable irrigation method, fertilization system The planting density and the prediction of crop productivity under the change of external environment provide scientific basis for the application and popularization of cotton without film dropper in southern Xinjiang.

At this stage, most of the simulation experiments conducted on the field scale in the study of soil water, heat and salt transport are largely affected by the complex and changeable weather. The crop model inputs data before the initial stage. The simulation data of the inversion module in the model is full of a lot of assumptions. Due to the uncertainty of the field data, the finite element hypothesis theory between soils causes the complex boundary conditions, It affects the field and simulation in the field of water-saving irrigation, reducing the accuracy of the model to a certain extent. Therefore, the use of Aquacrop simulation in the field of water-saving irrigation will be affected by the inherent soil properties and planting patterns, and the values observed in the field and the parameters of the model will be different.

Based on the situation of soil texture, irrigation method, irrigation frequency and irrigation system, the application of Aquacrop model in data simulation and verification of soil water movement, heat transfer and soluble matter transfer can be seen from the research results of most scholars that the simulation value and the actual measured value are relatively well matched. On the one hand, the results can reflect that Aquacrop model can simulate crop yield with good accuracy, On the other hand, this model can also be used to simulate and evaluate crop irrigation systems under different irrigation frequencies, which can not only save time for field experiments, but also provide a solid foundation for regional feasibility analysis and reflect the potential value of this project.

In terms of irrigation system, Aquacrop model is still mostly used for annual crops, and few people are involved in perennial crops. Although much has been done to the application of this model in hydrothermal salinity, it still remains in the use of unilateral models, and has not been combined with other growth models for comprehensive analysis. There is still a lack of experience in this regard. Therefore, this model can be combined with other models to the extent of previous ideas, so as to achieve multi-directional verification. Not only can we see the real-time dynamic changes of the underground, We can also see the growth and development process and yield change of the aboveground part. We should also take full account of the interaction between different media. In the verification of different media, we can combine today's advanced technologies, such as remote sensing and 3S technology, to improve the accuracy of the model, so as to achieve the goal of more perfect models.

5. Concluding Remarks

(1) Crop model simulates the growth index and yield of crops in the whole growth period in time step. Based on the changes in different time periods, the influencing factors affecting crop growth can be quantitatively analyzed.

(2) In simulation of rain-fed area, there is no crop physiological sub-module, nutrient balance module and water and nutrient interaction module, so it cannot simulate crop growth well under water-salt stress, temperature stress, etc. Therefore, it is necessary to pay attention to parameter checking when stress exists.

(3) Based on the limitation of single model, coupling between multiple models can be considered to continuously modify model parameters to improve the accuracy of the model.

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