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Numerical experiments for the impacts of temperature and precipitation variation on the growth and development of winter wheat

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Abstract— The growth process of winter wheat was simulated by CERES-wheat model assuming the daily temperature increase −1, 0, 1, 2℃ and daily precipitation increase −20, −10, −5, 0, 5, 10, and 20 percent, respectively. The case study site is Zhenjiang City of Jiangsu Province in the east China. Simulation results show that the impacts of temperature variation on winter wheat is stronger than that of precipitation. Climate warming would speed development rate and shorten phenological period. In general, the adverse effect of climate change on grain yield is greater than that of its beneficial effect, especially when the climate becoming cooler and dryer. The increase of temperature and decrease of precipitation would reduce the plant extractable soil water content.

Keywords: climate change; winter wheat; CERES-wheat model.

INTRODUCTION

Climate change because of the enrichment of CO_2 and other greenhouse gases in atmosphere and its implications has been more and more concerned by researchers. Agricultural production is very sensitive to climate change. In conjunction with atmosphere general circulation model (GCM) with crop model, that is, simulation crop's behavior based on the changed climatic scenarios predicted by GCM, is one of the most efficient approaches for the effect of climate change (Zhang, 1991). Some experiments and analysis have been conducted (Zhao, 1990) for the impact of climate warmer 1℃ and 2℃ for various periods of crop growing season on winter wheat planted at different dates.

In this study, the impacts of temperature and precipitation variation and their combination on growth, development and grain yield of winter wheat were analyzed by CERES-wheat model.

METHODOLOGY

The crop model for wheat in this study is the crop estimation through resources and environmental synthesis model, abbreviated as CERES-wheat model, developed by an international and interdisciplinary team of scientists for more than a decade. CERES-wheat model is a user-oriented crop process simulation model on daily time step, it considered the interaction between environmental factors and many bio-processes such as photosynthesis, respiration, phenology, initiation and growing processes of organs, soil water, evapotranspiration and nitrogen movement. Comparatively, the effect of temperature on bio-processes was simulated more detail than other environmental elements. However, some limitations of the model must be noted: first, the model did not consider the effect of catastrophic weather events, pests and weeds; second, the direct effect of CO_2 on photosynthesis and other bio-processes was not considered in this version of the model.

Zhenjiang City (32.2'N, 112.5'E), in the east of China, was selected as the case study site where some field experiments have been conducted. CERES-wheat model was tested and validated by observed data of four growing seasons, and the genetic parameters needed as input data of the model were determined and tested as well (Zhang ,1991).

Plenty of uncertainties and disagreements exist for climate change scenarios, especially for some specific regions, because of the enrichment of CO_2 and other greenhouse gases in the atmosphere. So in this study, several climate scenarios were used directly. Only were temperature and precipitation changed and other environmental elements maintain the same as in the initial conditions. Assuming the daily maximum and minimum temperature vary −1, 0, +1 and +2 ℃, and daily precipitation varies −20, −10, −5, 0, +5, +10, and +20 percent, respectively, totally 28 kinds of combinations (Table 1).

Table 1 Temperature and precipitation

Temperature treatments, ℃	Precipitation treatments, %						
	−20	−10	−5	0	+5	+10	+20
−1	1	2	3	4	5	6	7
0	8	9	10	11	12	13	14
+1	15	16	17	18	19	20	21
+2	22	23	24	25	26	27	28

In Table 1, the numbers from 1 to 28 represent the kinds of treatments. For example, treatment No. 1 represents a scenario of temperature decrease 1 ℃ and precipitation decrease 20 percent compared with initial condition, which is treatment No. 11 in Table 1.

RESULTS ANALYSIS

Phenological stages

The growing circle of winter wheat, from sowing, emergence, tillering, heading, enthesis to maturity, lasting about 210 days. The phenological stages of winter wheat which hardly dependent of soil water condition, is mainly determined by temperature, and which can be expressed approximately by thermal accumulation theory. The simulation results (Table 2) show that higher temperature can speed up the development rate and shorten the phenological durations, otherwise, lower temperature can slow down the development rate and prolong the phenological durations of winter wheat. The impact of each 1 ℃ temperature variation on the phenological duration is about 4 percent.

Table 2 The impact of temperature variation on phenological durations

Temperature treatments, ℃	Phenological duration variation			
	Sowing, days	Enthesis, %	Sowing, days	Maturity, %
−1	7.0	4.0	8.0	3.8
0	0.0	0.0	0.0	0.0
+1	−8.0	−4.6	−9.0	−4.3
+2	−17.0	−9.8	−16.0	−7.7

Grain yield and its structural elements

Fig. 1 is the impact of temperature and precipitation variation on grain yield. It shows that lower temperature and less precipitation will apparently decrease the grain yield of winter wheat, especially for the situations of rainfall decrease 20 percent. For the treatment No. 1, grain yield declines about 22 percent. Warmer and wetter climate can slightly increase grain yield.

So the adverse impact of climatic change on grain yield is more obvious than its beneficial effect, that probably because characteristic and agricultural artificial activities are much adopted to the present climatic condition and any climatic change would mean some mismatch between them and its unfavorable effect on crop would be more apparent.

According to the simulation results, grain number per ear and per unit planting area are related with temperature variation and hardly dependent on water treatments. They would decline about 10 percent if temperature lowered 1 ℃. The kernel weight would have more or less increase under cooler conditions if the precipitation reduced is not very much.

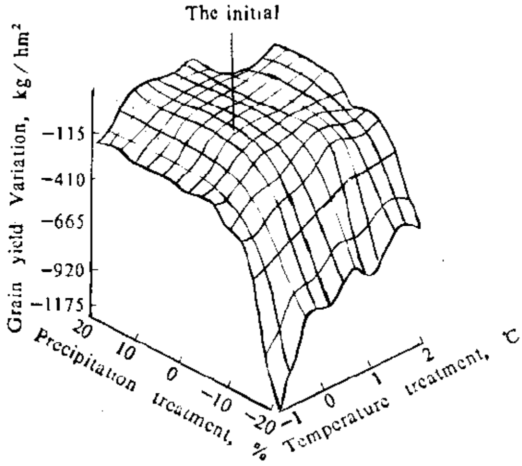

Fig. 1 The impact of temperature and precipitation variation on grain yield

Above and underground biomass

The simulation results show that the biomass of winter wheat is affected by temperature obviously, but that of precipitation is very slightly. Fig. 2 and Fig. 3 illustrate the impacts of temperature and precipitation treatments on variation processes of above and under ground biomass.

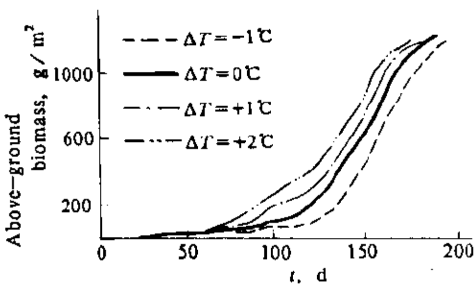

Fig. 2 The impact of temperature treatments on above ground biomass variation processes
(Day is the number of days from Nov. 1)

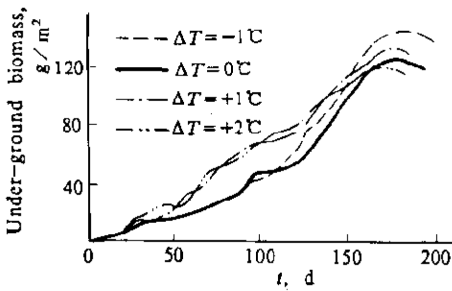

Fig. 3 The impact of temperature treatments on underground biomass variation processes

Fig. 2 shows that the weighting processes of above ground biomass will be delayed by lower temperature and be shifted forward by warmer climatic conditions. That is, temperature variation strongly affected the starting and ending dates of wintering stage which responding to a slower biomass growing period. But the difference of maximum value of above ground biomass which in initial conditions (treatment No. 11) is comparatively great, is small. For underground biomass, its maximum value was affected more apparently by temperature. Under higher temperature conditions, the growing process of root weight will be more consistent and without obvious slower growing period which responding to the wintering stage of wheat.

Leaf area index(LAI).

Similar to biomass, leaf area index is affected by temperature obviously. Fig. 4 illustrates the variation processes of LAI under different temperature conditions. If climatic condition is warmer, the date responding to maximum LAI will be earlier, the variation curve of LAI will be more consistent and smoother, and the duration of high value of LAI spanned will be longer, which takes advantage to effective photosynthesis, but the maximum value of LAI will be lower.

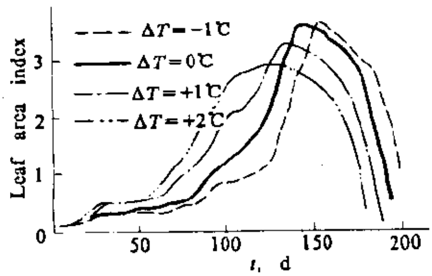

Fig. 4 The impact of temperature treatments on LAI variation processes

Plant extractable soil water (PESW)

Plant extractable soil water is defined as:

$$PESW = \begin{cases} DUL - LL & (SW \geqslant DUL) \\ SW - LL & (DUL \geqslant SW > LL) \\ 0 & (SW < LL) \end{cases} ,$$

Where *DUL*, *LL* and *SW* are field capacity, withering point and present moisture of soil, respectively, with the unit of centimeter. $\Delta PESW$ represents the difference of the *PESW* under certain treatment conditions and the initial (treatment No. 11).

Higher temperature and lesser precipitation will decrease *PESW*. Table 3 shows the impact of temperature variation on $\Delta PESW$.

Table 3 The impact of temperature variation on $\Delta PESW$

Days	Temperature treatment, ℃			
	−1	0	+1	+2
50	0.1	0.0	−0.3	−0.5
100	0.4	0.0	−1.0	−1.6
150	0.7	0.0	−2.0	−2.8
165	0.8	0.0	−2.2	−3.1
175	1.1	0.0	−2.3	−3.5

The more the temperature variation, the greater the absolute value of *PESW*, especially in the later crop growing stages, but their relationship is nonlinear. The impact of temperature variation on *PESW* is directly through changing potential evapotranspiration and through affecting the crop growth and development process (such as phenology, biomass and *LAI*) indirectly.

Table 4 The impact of precipitation variation on *PESW*

Days	Precipitation treatments, %						
	−20	−10	−5	0	+5	+10	+20
50	−2.7	−1.2	−0.5	0.0	0.2	0.3	0.4
100	−3.0	−1.3	−0.6	0.0	0.0	0.0	0.0
150	−4.2	−1.9	−0.9	0.0	0.3	0.6	1.2
165	−4.4	−2.0	−0.9	0.0	0.3	0.7	1.4
175	−5.0	−2.5	−1.2	0.0	0.6	1.2	2.4

Table 4 shows the impact of water treatment on Δ*PESW*. The increase of Δ*PESW* responding to the decrease of precipitation is almost in a linear relationship, but the decrease of Δ*PESW* responding to the increase of precipitation is not so obvious, this phenomena probably associated with the case study site, Zhenjiang, where the climate is relatively wet (in the growing season of winter wheat, approximately from November first of last year to May thirty first of present year, average temperature is 9℃, the total precipitation of multi-year average during this period is 420 mm).

The impact of temperature and precipitation on *PESW* are direct and indirect, and some variations exist for different growing stages of crop. The influence of temperature lower 1 ℃ on *PESW* is near to that of precipitation increase 10 percent, and the impact of temperature higher 1 ℃ on Δ*PESW* is near to that of precipitation increase 10 percent. Otherwise, *PESW* variation affected by temperature lower 1 ℃ nearly can be offset by that of precipitation decrease 5 percent, and *PESW* variation affected by temperature higher 1 ℃ almostly can be offset by that of precipitation increase 10 percent.

CONCLUSION AND DISCUSSION

The effect of temperature and rainfall variation on winter wheat based on the simulation results of CERES-wheat model analysed above can be concluded as:

The impact of temperature variation on winter wheat is more apparent than that of precipitation. That may associated with the climatic condition of case study site and the mechanism considered in the model.

Higher temperature can speed development rate and shorten phenological durations. Quantitatively, it is about 4 percent for each 1 ℃ temperature variation.

Quantitatively, the adverse effect of temperature and precipitation variation on grain yield is greater than that of their beneficial effect, especially under higher temperature and dryer conditions.

In the warmer climatic conditions, the wintering period of wheat will be not apparent, the variation processes of biomass and leaf area index will be more consistent and shifting forward for a period of time, especially for *LAI*, it may take the advantage of increase effective photosynthesis and elevating biomass accumulation.

For the plant extractable soil water, it would decline if temperature increase and precipitation decrease. The impact of temperature variation (increase or decrease) of 1℃ is about the same as that of precipitation varying (decrease or increase) 10 percent. If temperature decrease 1 ℃ and precipitation decrease 5 percent at the same time, or temperature increase 1 ℃ and precipitation increase 10 percent at the same time, *PESW* would be almost unchanged.

The results of simulation show that the impact of cooler and dryer climatic condition on crop is rather badly. In general, if the climate change can enrich the climatic resources such as the climate becomes warmer and wetter, it would take advantage of crop production, at least after some necessary adjustment of the management activities. Otherwise its effect would be more adversely.

This study attempts to provide some information adapting to climate change actively. Generated results above, although quantitatively, are a case study at only one site, and some limitations of the input data and crop model exist which would affect the simulating results. Two points must be noted specifically: first, the crop model has been used did not consider the direct effect of CO_2 on crop growth and development. Second, the simulated results above did not consider the change of agricultural production activities which would be inevitable to adapt to the climate change.

REFERENCES

Zhang Yu, Shandong Meteorology, 1991, 3:1.
Zhao Siqiang and Zhang Yu, Journal of Environmental Sciences (China), 1990, 2 (4) : 11.
Zhang Yu and Zhao Siqiang, Agricultural Meteorology, 1991, 12 (3):11.

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