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The Impact of Climate Change on Maize Phenophase and Crop Water Requirement in the Heihe River Basin, Northwestern China

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Abstract

Climate change is likely to change crop phonological characteristics, which will then affect crop water requirement. The identification of phenophase change and its impact on crop water demand has become a key factor in agricultural water resources management and confronting climate change. The study adopts climatic tendency rate method, active accumulated temperature threshold method and synthetic estimate method recommended by FAO to determine the phenophase and water requirement change for spring wheat and spring maize in Heihe River Basin. The study shows that: a) climate change advances the phenology of wheat and maize for all growth stages in Heihe River Basin, and the entire growth period of the crops is reduced by 7 days; b) water requirement for entire growth period impacted by climate change (without consideration of phenology) is demonstrated by the increase of 26.1mm, 6.0% up for wheat and the increase of 5.6mm, 0.7% up for maize; c) water requirement in entire growth period impacted by climate change (with consideration of phenology) is featured in the decrease of 50mm, 11.5% down for wheat and the decrease of 13.4mm, 1.8% down for maize.

Keywords: climate change, crop phenology, crop water requirement, Heihe River Basin

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INTRODUCTION

Global climate has been experiencing a time of warming characterized change in recent one hundred years (Allen et al. 1998). This can be traced from the change occurring to crop phenophase, the most immediate evidence in agriculture, which in turn disrupts agriculture water supply and demand balance.The research of phenophase has been popular for agricultural production, irrigation management and cost estimate reference. Therefore, the research of phenophase based crop water requirement under climate change is of significant importance to agricultural and terrestrial ecosystems management and in particular, the research will provide supports for agricultural water supply and demand. Taking into account of Heihe River Basin's unique geographical location and its important role in agricultural production of Zhangye City, the phenophase based crop water demand may provide a better understanding of crop water requirement mechanism response to climate change, identify the water demand mechanism and thus provide scientific reference for food security.

The present studies on impact of climate change on crop growth phenophase mostly set their precondition on temperature versus climate change response. These studies usually take reference of plenty of phenological observation data, analyze crop growth thermal condition and investigate crop phenophase change. Although the research method adopted by these studies is extensively applied and proved in many fields (IPCC 2007), the application is limited where there is no measured or observed phenology data. With respect to irrigation required water under climate change, these studies tend to limit their research on two respects, i.e., relationship between agricultural climate factor and crop required water change and change of crop required

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water under temperature rising scenario, however, rare research in these studies has been made to the impact of climate change on crop growing process or the impact of phenophase change on crop required water quantity. Therefore, these studies are unable to effectively identify the climate change impact on crop irrigation water requirement. This study uses the accumulated temperature threshold recorded in crop growing period to compensate the insufficiency of phenological observatory data, integrates for the first phenophase and crop itself growth change under climate change, systematically identifies the space-time evolution characteristics of phenophase and crop required water quantity under climate change and further proposes new approach of research on impact of climate change on crop required water.

STUDY AREA AND METHODS

Study Area

Heihe River is second longest endorheic river in China with the river basin lying at 98°E - 102°E and 37°N - 42°N, covering an area of 14.29×103 km^2. The river originates from Qilian Mountain in Qinghai Province, flows through Qinghai Province and Gansu Province and ends in Inner Mongolia. In upstream reaches, the annual mean temperature is less than 2℃ and annual precipitation is 350mm. In middle reaches, annual precipitation is only 140mm, annual mean temperature ranges from 6℃ to 8℃, annual daily sunshine duration ranges from 3000 to 4000 hours and annual evaporation is as high as 1,410mm. In downstream reaches, annual precipitation is only 47mm, annual daily sunshine duration is 3,446 hours and annual evaporation is as much as 2,250mm.

Wheat, maize and potato as main crops are planted in Heihe River Basin, which accounts for 70% of all cereal crops here. Spring wheat and spring maize are either individually planted or inter-cropped. Main planting areas are mostly distributed in the basin's dry farmland areas like Jinta, Jiuquan, Zhangye and Shandan in middle reaches of the basin, and dry farmland in middle reaches is one of the most important bases of food and vegetables production in western China. It is necessary to point out that Zhangye District with less than 5% cultivated land of Gansu Province, provides 35% of total commercial food supply in the province, thus the district plays an important role in agricultural production. Among crops planted in the basin, wheat is sowed on around March 20th and harvested on around July 20th with growth period of generally 120 days and maize is seeded on around April 13th and harvested on around September 17th with the growth period of generally 160 days.

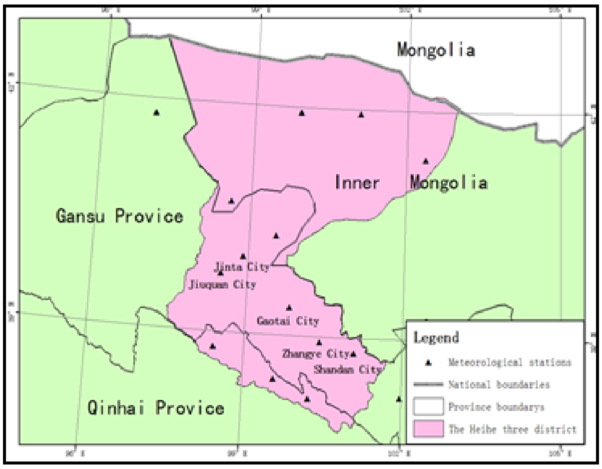

Fig. 1. The distribution map of meteorological stations in the Heihe River Basin

Data

The daily data in the study is collected from the climate datasets of International Exchanging Stations of China provided in China Meteorological Sharing Service System. The distribution map of meteorological stations in the Heihe River Basin is shown in **Fig. 1**. Daily average temperatures at five weather stations and meteorological points in main cropping area of middle reaches of Heihe River Basin, where complete weather data and representative information is available, as reference for the study. The data is collected from January 1st 1961 to December 31st 2010. Crop phenology data is mainly collected from the dataset of China crops growth information.

Methods

Determination of wheat growth threshold

The onset day of active accumulated temperature with daily average temperature of ≥7℃ is the most suitable time for wheat sowing (Nelson et al. 2009). Taking into account of the actual weather condition of the subject area, the study takes the average temperatures of daily average temperatures for 5 consecutive days as indicators to define the onset and end of crop growth, accordingly, the onset day of active accumulated temperature (AT) with daily average temperature of ≥7℃ for 5 consecutive days is treated sowing time of wheat growth period. Meanwhile, with reference to ≥10℃ active accumulated temperature threshold (given in **Table 1**) relevant to wheat growth period, wheat begins seedling when the accumulated temperature is up to 102℃, which is selected as threshold for start of wheat seedling stage; throughout

Table 1. The ≥10°C accumulated temperature thresholds of wheat at different growth stages

sowing - seedling stage	seedling- tillering stage	tillering - jointing stage	jointing- heading stage	heading-dough stage
102°C	200°C	295°C	380°C	700°C

sowing-seedling-tillering stages, when accumulated temperature is up to 302°C, seedling begins tillering, which is selected as threshold for start of wheat tillering stage; in the same way, the threshold accumulated temperatures identified for wheat jointing stage, heading stage and dough stage are 597°C, 977°C and 1677°C respectively.

Determination of maize growth threshold

Lower limit temperature is 6-8°C and most suitable temperature is 8-10°C for maize seed (Rosenzweig and Pany 1994). On the basis of the weather condition of the subject area, the study takes the first active accumulated temperature (AT) with daily average temperature of ≥10°C of first 5 consecutive days as seeding time of local maize planting. Meanwhile, with reference to ≥10°C active accumulated temperature threshold relevant to maize growth period, maize begins seedling when the accumulated temperature is up to 224°C, which is selected as threshold for start of maize seedling stage; in the same way, the threshold accumulated temperatures identified for maize silking stage and dough stage are 1,724°C and 3,048°C.

Periods division of climate change

With regard to response to climate change, temperature forecasting model is more precise than other meteorological elements (Todico and Vergni 2007) (e.g. precipitation) and temperature is one of key elements affecting crop growth, therefore the study takes temperature as division reference to determine the critical points. Sudden change of temperature in Heihe River Basin was M-K measured and MMT measured both in 1991. Little change of temperatures was observed from 1961 through 1991 under the impact of climate change, however, the same was seen significant for the period from 1992 through 2010 under the impact of climate change. So 1961-1991 is selected as base period and 1992-2010 as comparison period 1 in the research to investigate the impact of climate change on crop phenophase and water requirement. The study defines 1992-2010 without consideration of phenological change as comparison period 2 in order to have a better understanding of the research on phenophase versus crop water requirement.

Table 2. Different growth stages of crop coefficient

Spring Wheat	crop coefficient	Spring Maize	crop coefficient
sowing -seedling	0.32		
seedling-tillering	0.48	sowing -seedling	0.40
tillering -jointing	0.76	seedling-silking	1.18
jointing-heading	1.05	silking-dough	0.80
heading-dough	0.84	growth period	0.80
growth period	0.84		

Calculation of crop phenophase

The study adopts accumulated temperature threshold to calculate the growth dates of wheat and maize and integrates climate tendency rate to calculate phenological change.

$$\theta_i = \frac{n \times \sum_{j=1}^{n}(j \times P_{ij}) - \sum_{j=1}^{n} j \times \sum_{j=1}^{n} P_{ij}}{n \times \sum_{j=1}^{n} j^2 - \left(\sum_{j=1}^{n} j\right)^2}$$

In which, n is the number of years in analyzed period; Pij, is the value of jth year of ith statistic characteristics; and θi, is the slope of ith statistic characteristics tendency curve; Where, θi>0 indicates phenophase changes behind schedule and θi<0 indicates phenophase changes ahead of schedule.

Calculation of crop required water quantity

Water quantity required by crops can be obtained with comprehensive method. In this regard, reference is made to the formula recommended by Food and Agriculture Organization of United Nations (FAO):

$$ET_P = K_C \times ET_O$$

Where, ET_P, is crop required water quantity (mm/day) with abundant water supply; K_C, is crop coefficient (shown in **Table 2**) ; and ET_O, is the reference crop evapotranspiration (mm/day).

RESULTS AND DISCUSSION

Crop Phenophase Change in Growth Period

Onset date of wheat growth period is shown in **Table 3** and the results are as follows: the phenology of wheat growth period is advanced to different extent; sowing date of base period is between March 25th and 27th, comparison period 1 is advanced by 10 days, and annual average sowing date is between March 17th and 19th; seedling date of base period is between April 22nd and 24th, comparison period 1 is advanced by 10 days; base periods of tillering stage, jointing stage, heading stage and dough stage: between Mary 8th and 10th, between May 28th and 30th, between June 17th and 19th and between July 20th and 21st respectively; comparison periods 1: advanced by 12 days, 13 days, 14 days and 17 days respectively.

Table 3. The phonological change of wheat at different growth stages in main growing areas

Wheat	Base period	Comparison period 1	Multi-year average period
Sowing stage	March 25-March 27	March 15-March 17	March 17-March 19
Seedling stage	April 22-April 24	April 12-April 14	April 12-April 14
Tillering stage	May 8-May 10	April 27-April 29	April 28-April 30
Jointing stage	May 28-May 30	May 15-May 17	May 17-May 19
Heading stage	June 17-June 19	June 3-June 5	June 5-June 7
Dough stage	July 20-July 21	July 2-July 4	July 6-July 8

Table 4. The days of wheat at different growth stages in main growing areas

Growth period(d)	sowing - seedling	seedling-tillering	tillering - jointing	jointing-heading	heading-dough	growth period
Base period	28	16	18	22	32	116
Comparison 1	28	15	18	19	29	109
Multi-year average	26	16	17	21	31	111

Table 5. The phonological change of corn at different growth stages in main growing areas

Maize	Base period	Comparison 1	Multi-year average
Sowing stage	April 21	April 12	April 9
Seedling stage	May 14	May 4	May 4
Silking stage	July 25	July 16	July 18
Dough stage	September 27	September 11	September 12

Table 6. The days of corn at different growth stages in main growing areas

Growth period	sowing - seedling	seedling -silking	silking -dough	growth period
Base period	23	72	64	159
Comparison 1	22	73	57	152
Multi-year average	25	75	56	156

Length of wheat growth period is as follows (**Table 4**): days of different stages of wheat growth period change slightly under climate change; sowing -seedling stage and tillering – jointing stage remain unchanged with 28 days and 18 days respectively; seedling-tillering stage, jointing-heading stage and heading-dough stage are shortened from 16 days, 22 days and 32 days to 15 days, 19 days and 29 days respectively. The entire growth period of wheat is reduced by 7 days.

Onset date of maize growth period is as follows (**Table 5**): phenology of wheat growth period is advanced to different extent; seeding date of base period is April 21st, comparison period 1 is advanced by 9 days on average; seedling date in base period: May 14th, comparison period 1 is advanced by 10 days on average; base silking date of base period is July 18th, comparison period 1 is advanced by 9 days on average; base dough date of base period is September 27th, comparison period 1 is advanced by 16 days.

Length of maize growth period is as follows (**Table 6**): days of different stages of maize growth period change slightly under climate change, seeding -seedling stage is reduced from 23 days to 22 days; seedling-silking stage is extended by 1 day to 73 days; silking – dough stage is shortened by 7 days from 64 days. Therefore, the entire growth period of maize is reduced by 7 days.

The different growth stages of both wheat and maize growth are advanced differently and entire growth period of both is shortened by 7 days. Phenophase change mainly rests with kinds of crops and local temperature condition. Spring seeded crops growing in the area commonly are selected for study without differentiating their varieties. Thermal flux is relatively high in the major planting areas of the center part of Heihe River Basin under climate change condition as a result of unique geographical condition of Heihe River Basin, i.e., plain and desert dominating the central part and hills lying at both sides, thus temperature in the basin is more sensitive to climate change than in other areas of same latitude. Should lower limit temperature of crop biology remain unchanged, the rise of temperature will advance ≥10°C accumulated temperature to crop growth period threshold, so onset date of crop growth period will be bound to be advanced. Relevant research indicates that spring phenophase will be advanced averagely by 2 days for spring average temperature rise of 0.5°C in China and by 3.5 days for 1°C rise. Moreover, ≥10°C accumulated temperature tends to be shortened against the background of global warming in recent years and crop physiological and biochemical response speed will be increased by 1 to 2 times for 1°C temperature rise, which will result in shortening crop growth duration.

The change of growth duration of wheat and maize planted in the basin has certain impact on agricultural production, field management and irrigation cost estimation. The advancing of growth dates, on one hand, the most suitable seeding dates, the number of grains of a grain ear, grain ears of unit area and earing rate change compared with previous planting structure, frost resistance under different periods, frost by low temperature and leaves and seedling affected area are affected to certain extent; on other hand, water required for irrigation of wheat and maize changes, water supply and distribution plan needs amendment, water for irrigation needs compensation and agriculture development layout changes. Therefore, under climate change, on the basis of adaption to climate change tendency, we should adjust agricultural irrigation layout in logical way, distribute water resources in reasonable manner and try to achieve sustainable development of agriculture.

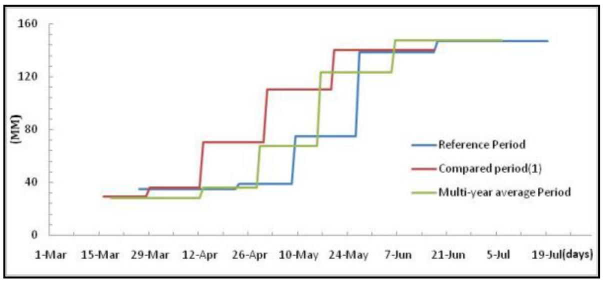

Fig. 2. The comparison chart of wheat water demand

Table 7. The comparison of wheat water requirement for wheat

Growth period	Base period (mm)	Comparison 1 (mm)	Comparison 2 (mm)	Multi-year average (mm)
sowing-seedling	35.1	29.0	36.8	27.9
seedling-tillering	39.1	35.8	44.6	35.9
tillering - jointing	75.1	70.0	69.4	67.2
jointing-heading	138.4	110.2	130.2	123.1
heading-dough	147.1	139.9	179.9	147.5
growth period	434.8	384.7	460.9	401.6

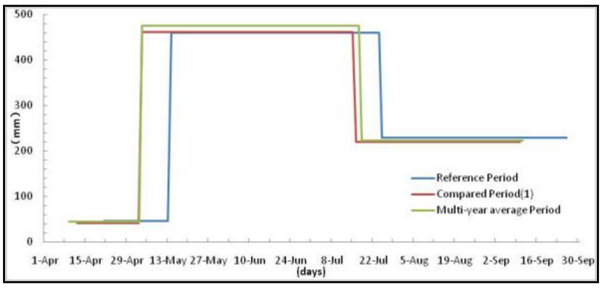

Fig. 3. The maize water demand comparison chart

Table 8. The comparison of wheat water requirement for Maize

Growth period	Base period (mm)	Comparison 1 (mm)	Comparison 2 (mm)	Multi-year average(mm)
sowing-seedling	46.1	41.1	46.4	44.3
seedling-silking	460.5	461.9	470.1	474.8
silking-dough	229.2	219.4	224.9	222.4
growth period	735.8	722.4	741.4	741.5

Change of Water Requirement in Crop Growth Period

Change of water requirement for wheat

Change of Wheat Water Requirement is shown in **Table 7** and **Fig. 2**. Climate change advances the water requirement onset date of entire wheat growth period by 10 days; the period of requiring water is shortened by 7 days; required water quantity is reduced by 50mm, dropping11.5%. Water required in comparison period 2 is increased by 26.1mm compared with the one in base period, 6.0% rising, i.e., the required water quantity tends to rise should change of phenophase be not considered by conventional water requirement calculation. Changes of water requirement for different stages of wheat growth period are: at sowing-seedling stage, 35.1mm required in base period, decrease by 29.0mm in comparison period 1 with 17.4% drop; at seedling-tillering stage, 39.1mm required in base period, decrease by 3.3mm in comparison period 1 with 8.4% drop, in the same way, the drops of water requirement at tillering-jointing stage, jointing-heading stage and heading-dough stage are 6.8%, 20.3% and 4.9 % respectively under climate change.

Change of water requirement for maize

Change of Wheat Water Requirement is shown in **Table 8** and **Fig. 3**. Climate change advances the water requirement onset date of entire maize growth period by 9 days. The period of requiring water is shortened by 7 days. Required water quantity is reduced by 13.4mm for 1.8% down. Water required in comparison period 2 is increased by 5.6mm against that in base period 0.7% up. Changes of water requirement for different stages of maize growth period are: at seeding-seedling stage, 46.1mm required in base period, decrease by 41.1mm in comparison period 1 with 10.8% drop; changes of water requirement at seedling-silking stage and silking-dough stage are increase by 0.3% and decline by 20.3% respectively under the impact of climate change.

Compared with base period, water requirement changes in comparison period 2 in entire growth period of wheat and maize in middle reaches of Heihe River Basin show that wheat required water rise by 6% and maize required water rise by 0.7%. The variation of water requirement is closely related with temperature rise affected by local climate change. Relevant study shows temperature has risen by 1.8-4℃ in northwestern part of China and by 0.3-1.4℃ in Zhangye District in middle reaches of Heihe River Basin since 1980s. The study also shows wheat required water quantity will be increased by 19.2-20mm for temperature rise of 1℃ (Yao and Lin 1965). In addition to the change, the rising magnitude of water requirement of maize is evidently lower than that by wheat, which can be explained by the fact that summer seeded crops is less sensitive to climate change than spring sowed crops.

Compared with base period, water requirement changes in comparison period 1 in entire growth period of wheat and maize in middle reaches of Heihe River Basin indicates that wheat required water quantity reduced by 50mm/a for 11.5% down and maize required water quantity reduced by 13.4mm/a for 1.8% down.

The change of phenophase based crop water requirement under climate change mainly attributes to that: on one hand, the advancing and shortening to different extent of growth period phenology of wheat and maize under the impact of climate change; the decline of temperature, reduction of evapotranspiration, decline of required water quantity within growth period of spring crops and summer crops as the result of advancing of growth period when crop coefficient remains unchanged; on the other hand, the shortening of wheat and maize growth period due to temperature rise, bound to lead to decline of required water quantity in crop growth period.

Phenological change of wheat and maize growth period and water requirement change affects crop planting, irrigation cost evaluation, agricultural structure and planting system. The advancing of most suitable sowing dates of wheat and maize requires the proper adjustment of regional industrial structure and planting system. The selection of most suitable crop sowing period will effectively promote production and effectively protect crops from frost and pest. The change of water requirement at different stages of crop growth period in Heihe River Basin recommends reasonable adjustment to water supply in order to mitigate supply-demand conflict and the planting area of crops prone to climate change should be reduced to mitigate the pressure of crops to water resources and to better respond to climate change.

CONCLUSIONS

Climate change impact on heihe river basin wheat and maize phenophase and water requirement in Heihe River Basin, the new approach tries to provide new reference for preparing agricultural irrigation strategy. Main conclusion of the study includes the following:

The study adopts accumulated temperature threshold method to calculate and obtain annual average planting dates of major crops in Heihe River Basin. For wheat, the planting dates vary from March 17th to 19th with growth duration of 111 days; for maize the planting date is April 9th with 159 days growth period. There are almost no difference between the theoretically calculated results and the actually observed information, i.e., planting date March 20th and growth period 120 days for wheat, planting date April 13th and growth period 160 days for maize, which demonstrates the application of accumulated temperature threshold method is feasible for calculation of onset dates and length of growth period. Growth period of both wheat and maize in Heihe River Basin under climate change is advanced to different extent according to the calculation by adopting accumulated temperature threshold method and climate tendency rate method: wheat sowing stage, seedling stage, tillering stage, jointing stage, heading stage and dough stage are advanced by 10 days, 10 days, 12 days, 13 days, 14 days and 17 days respectively and entire growth period is reduced by 7 days; maize seeding stage, seedling stage, silking stage and dough stage are advanced by 9 days, 10 days, 9 days and 16 days respectively and entire growth period is shortened by 7 days.

Under the impact of climate change, in entire growth period of wheat, onset date of water requirement is advanced by 10 days, duration of water requirement is shortened by 7 days, required water quantity is reduced by 50mm/a with 11.5% down; in entire growth period of maize, onset date of water requirement is advanced by 9 days, duration of water requirement is shortened by 7 days, required water quantity is reduced by 13.4mm/a with 1.8% down.

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REFERENCES

Allen RG, Pereira LS, Dirk R (1998) Crop evapotranspiration guidelines for computing crop water requirements. FAO Irrig And Drain Paper 56. Rome.

IPCC (2007) Climate Change 2007: The Physical Science Basis-Summary for Policymakers, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: 1-21.

Nelson GC, Rosegrant MW, Koo J (2009) Climate Change: Impact on Agriculture and Costs of Adaptation. Washington DC: International Food Policy Research Institute: 2-14.

Rosenzweig C, Pany ML (1994) Potential impact of climate change on world food supply. Nature, 367: 133-138.

Todico F, Vergni L (2007) Climatic change in Central Italy and their potential effects on corn water consumption. Agricultural and forest meteorology, 8.

Yao LQ, Lin W (1965) China main varieties of rice and wheat cotton growing season accumulated temperature. Acta Agronomica Sinica, 4: 157-169.