*Journal of Environmental Sciences*, Vol. 5, No. 2, pp. 176–185, 1993 ISSN 1001-0742

# Impacts of climate change on wheat development and production in the northern China*

Gao Suhua, Guo Jianping and Pan Yaru

Chinese Academy of Meteorological Sciences, Beijing 100081, China

**Abstract** — In this paper, impacts of climate change on wheat development rate and production in the northern China are discussed. The results show that the temperature is a controlling factor of development rate but the precipitation is not. The higher the temperature is, the faster the development and the shorter development period will be. Without consideration to varieties and cropping system, meteorological yield of winter wheat would decrease 170.40, 134.25, 98.70 and 97.20 kg/hm$^2$ in the north China and 13.97, 7.95, 39.60 and 19.80 kg/hm$^2$ in the northwest China compared with that in 1950s, 1960s, 1970s and 1980s, respectively, when the $CO_2$ concentration in the atmosphere is doubled. In drought and semi-drought regions, the spring wheat yield would drop with the temperature rise in and raise with the precipitation increase. The influence of temperature on weight of leaf and stalk is also remarkable.

**Keywords:** climate change; wheat; development rate.

## INTRODUCTION

Meteorological condition is one of the important environmental factors influencing crop development, and its variation may affect crop growth directly. Beginning from this century, the influence on global ecological environment of rapid development of industry and human activities are even more greater. The more considerable greenhouse effect caused by the increase of $CO_2$ content in the atmosphere has attracted general interest, especially, its impact on the agriculture on that studies and approach have been done by scientists all over the world. In this paper, impacts of climate change on wheat (including winter wheat and spring wheat) growth and production in the northern China are discussed.

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* The programme of impacts of climate change on winter wheat production in the north and northwest of China was directed by Zhao Siqiang, and Wang Jianling and Pan Yaru took part in it; Huang Feng and Dong Yongxiang participated in the work on spring wheat.

## IMPACTS OF CLIMATE CHANGE ON WHEAT DEVELOPMENT

*Impacts on winter wheat development in the north China*

Winter wheat has to pass through many development periods from sowing to maturity. The length and its influential factors of each period are different. The days ($D$) of each period is recorded in agrometeorological observation, and development rate ($V$) is the reciprocal of D. That is

$$V = 1/D. \quad (1)$$

Table 1 (Guo, 1991) lists the relationships between development rate and meteorological factors. All the equations in Table 1 are passed 0.01 significant test level of $F$.

**Table 1 Relationships between development rate and meteorological factors**

| Development period | Models |
|---|---|
| Sowing-emergence | $V = -0.1565 + 0.1035 \ln(T)$ |
| Emergence-tillering | $V = 0.0211 \exp(0.0795T - 0.0051R)$ |
| Tillering-overwintering | $V = 0.0987 - 0.0121T - 0.0383/T + 0.0043/T^2$ |
| Overwintering-turn green | $V = 0.0143 \exp(0.0657T - 0.0056R)$ |
| Turn green-jointing | $V = 0.0261 - 0.1836/T^2$ |
| Jointing-earing | $V = 0.0429 \exp(0.0107T - 0.0004R)$ |
| Earing-maturity | $V = 0.0108 \exp(0.0441T - 0.0003R)$ |
| Sowing-maturity | $V = 0.0034 \exp(0.0292T - 0.0004R)$ |

As it is shown in Table 1, the development rate from sowing to emergence, from tillering to overwintering, and that from turn green to jointing is only related to mean temperature, while in other periods, the rate also has a slight negative relationship with precipitation. It is suggested that the more the precipitation is, the slower the development or the longer period will be.

Fig. 1 shows the impacts of climate change on development rate of winter wheat from sowing to maturity, from which, it is clear that temperature is still a controlling factor of development rate but the precipitation in whole life is not. In general, 1℃ variation of mean temperature over the whole life may correspond a variety of about 0.0001 in development rate or 6−8 days change in the period. Consequently, providing the mean temperature is 3℃ higher, development rate would change from 0.0038 in 1980s to 0.0042, and the period would shorten about 25 days and change from 263 days in 1980s to 238 days. In the contrast, if the mean temperature drop 3℃, the development rate would decrease to 0.0035 and the period of whole life would increase about 23 days to 286 days. During the whole life of winter wheat, higher temperature in the former stages of nutritive growth is favorable to nutrition growth, dry matter accumulation, tillering efficiently, surviving winter safely, reducing the rest period, and raising the utilization ratio of other resources (radiation, water, fertilizer and so on), that will result in a higher production. However, in the later stages of reproduction growth, higher temperature would result in fast development and short duration, this would frequently cause the injuries to the plants in their latter growing stages by much higher temperature which may compel their maturity and dry hot wind. Accordingly, the milking of grain grouting would be not enough, ratio of empty blighted spikes would be high, that is unfavorable to raising yield. Whereas, climate warming is favorable to winter wheat growth and production formation.

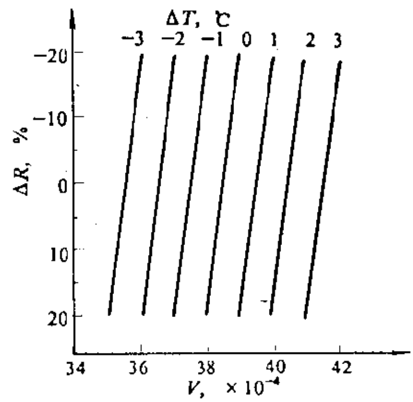


Fig. 1 The impacts of climate change on development rate

*Impacts on spring wheat development*

Table 2 (Pan, 1991) lists the relationships between development rate of spring wheat and meteorological factors in every stage in the northeast China. It can be seen from Table 2 that mean temperature is the main meteorological factor for spring wheat development. Although the forms and degrees of influence on development rate are different in individual stage, the development rate will be faster when mean temperature is higher. The impact of climate change on growth duration is shown in Table 3. From which we can see that providing the precipitation do not change, 1℃ higher in mean temperature would make 5.3 days shorter in growth duration and 1℃ lower with 5.6 days longer; while if temperature is constant, ±10 % variation in precipitation might be with only 0.3 and −0.5 days variety in growth duration. That implies that temperature is the directing factor for the development of spring wheat

Table 2 Development rate models in each stage

| Development period | Models |
|---|---|
| Sowing-emergence | $V = -0.0402 + 0.0329T - 0.0001R - 0.0042T^2 + 0.002T^3$ |
| Emergence-tillering | $V = 0.0377\exp(0.0168T - 0.0018R)$ |
| Tillering-jointing | $V = 0.0999 - 7.6732/T^2$ |
| Jointing-earing | $V = -0.3752 + 0.1524\ln(T)$ |
| Earing-maturity | $V = 0.0121\exp(0.0407T + 0.0005R)$ |

Table 3 The impacts of climate change on development period length

(unit: days)

| R, % | T, ℃ | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3 | 2 | 1 | 0 | −1 | −2 | −3 |
| 30 | −14.5 | −9.5 | −4.1 | 1.3 | 7.0 | 13.9 | 22.0 |
| 20 | −15.1 | −9.9 | −4.5 | 0.8 | 6.7 | 13.1 | 21.5 |
| 10 | −15.4 | −10.2 | −4.9 | 0.3 | 6.1 | 12.5 | 21.0 |
| 0 | −15.7 | −10.5 | −5.3 | 0.0 | 5.6 | 12.3 | 20.8 |
| −10 | −16.0 | −11.1 | −5.7 | −0.5 | 5.3 | 11.6 | 20.0 |
| −20 | −16.5 | −11.4 | −6.1 | −0.8 | 4.8 | 11.3 | 19.7 |
| −30 | −16.9 | −11.8 | −6.6 | −1.2 | 4.5 | 10.8 | 19.0 |

*Impacts of climate change on spring wheat development in drought and semi-drought regions*

Yongning in Table 4 (Huang, 1991) is a drought region with the annual precipitation of about 200 mm and the irrigation basis is good. Guyuan is a rainfall maintained agriculture region, where annual precipitation is about 480 mm, and without irrigation. The relationships between development rate and meteorological factors can be seen clearly in Table 4, where, $V$ is the development rate, $T$ is the mean temperature (℃), and $W$ stands for the soil water content (mm) summed in the depth of 0 to 50 cm at the beginning of the development stage plus the precipitation during this growth period.

It can be seen from the simulation models in Table 4 that the impacts of soil moisture change on spring wheat development is remarkable in drought and semidrought regions even if where is irrigated. Development rate is related with soil water supply in every periods except seeding stage. In irrigated agriculture region (Yongning), the rate is also related with the heat condition except the period from milk maturity to maturity. In rainfall maintained agriculture region (Guyuan), water supply is the only limitation factor to development rate from jointing to blooming because when the water requirement by plants is the greatest and natural precipitation is far from satisfactory with it for the wheat growth as soil water content was reduced due to evapotranspiration in former stages and rain season did not come. Under the present condition of water supply, growth duration of spring wheat will decrease with the increase in temperature, in general, 1 ℃ higher with 8 days shorter in irrigated agriculture region, and with 10 days in rainfall maintained agriculture region.

**Table 4 Development rate models of spring wheat in main development stages**

| Site | Yongning | | Guyuan | |
|---|---|---|---|---|
| Development stages | Development rate models | | Development rate models | |
| Sowing-three leaves | $V=-1.8321\times10^{-2}+8.0483\times10^{-3}T-2.0114\times10^{-4}\times10^{-4}T^2$ | 0.948** | $V=3.0713\times10^{-3}+4.2840\times10^{-3}T-9.1157\times10^{-5}T$ | 0.963** |
| Three leaves-jointing | $V=(-6.8045\times10^{-7}+1.0893\times10^{-3}W-3.6056\times10^{-6}W^{-2})e^{8.9650\times10^{-2}T}$ | 0.905** | $V=0.2719e^{-25.1122/T+9.194/W}$ | 0.971** |
| Jointing-booting | $V=-5.6819\times10^{-2}+1.1791\times10^{-4}(T.W)-2.4310\times10^{-8}(T\cdot W)^2$ | 0.972** | $V=0.0388e^{55.7643/W}$ | 0.934** |
| Booting-blooming | $V=-0.3388+3.1556\times10^{-4}(T.W)-5.9073\times10^{-8}(T\cdot W)^2$ | 0.917* | $V=0.0294e^{62.8863/W}$ | 0.946** |
| Blooming-milk maturity | $V=4.7190\times10^{-2}+1.0659\times10^{-5}(T.W)-1.4418\times10^{-9}(T\cdot W)^2$ | 0.960** | $V=0.1539e^{-31.5429/T}$ | 0.971** |
| Milk maturity-maturity | $V=6.8094\times10^{-2}-1.2321\times10^{-4}W$ | 0.931** | | |

* The significant level is through 0.05

** The significant level is through 0.01

Under the present heat condition, the effect of adding soil water content on development is very small. Whereas, the impacts of lost of water supply is remarkable in irrigated agriculture region (Soil water is satisfied with the requirement for spring wheat growth). Growth duration would be prolonged remarkably with the decrease of soil moisture. If soil water content decrease 15% by field water capacity, the duration would prolong 42 days, it makes the stage from blooming to maturity just met higher temperature season, following a seriously impact on grain production.

In rainfall maintained agriculture region, the growth duration has a tendency of prolonging with soil moisture increasing. Under the present heat situation, the duration would prolong 6 days if soil water content increase 20% by field water capacity and 20% decrease with 10 days shorter.

## IMPACTS OF CLIMATE CHANGE ON WHEAT PRODUCTION

### *Impacts on winter wheat production*

In this section, the impacts of climate change by double concentration of carbon dioxide in the atmosphere on winter wheat production will be discussed.

With OSU model developed by Zhao Zongci (Zhao, 1989), calculated values of mean temperature ($T_{12-2}$) and precipitation ($R_{12-2}$) in winter (Dec. –Feb.), mean temperature ($T_{6-8}$) and precipitation ($R_{6-8}$) in summer (June–Aug.), annual mean temperature ($T_{1-12}$) and annual precipitation ($R_{1-12}$) in six regions of China (in the northeast, north, middle, south, southwest and northwest of China) were given when $CO_2$ content be doubled in the atmosphere concentration. Combining the calculations of temperature and precipitation by OSU model in different regions and the regionalization of temperature and precipitation by China National Meteorological Center, following data were prepared:

(1) The 11 provinces or cities of main winter wheat areas in China were divided into two regions, in the north China (Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan, Anhui and Jiangsu) and in the northwest China (Shaanxi, Gansu and Xinjiang). Mean yield per unit area (kg/hm$^2$) of winter wheat in the north China and in the northwest China are computed by weighted averaging over 1951–1988 with the yield and area of each province or city in each region.

(2) The data of six meteorological factors in the north China and in the northwest China of $T_{12-2}$, $R_{12-2}$, $T_{6-8}$, $R_{6-8}$, $T_{1-12}$, and $R_{1-12}$ averaged over 1951 to 1989 are sorted out.

According to the analysis of linear and nonlinear regression between meteorological yield ($Y_W = Y - Y_t$, where $Y_W$ is meteorological yield, Y is real yield, and $Y_t$ represents the yield tendency) and the above six factors, factors passed relation test were selected, factors for model establishment were determined from those the ultimate with sieve method by successive regression. The results calculated by the models are listed in Table 5 (Zhao, 1991).

The yield tendency in Table 5 is the contribution of varieties, fertilizer, agricultural measurement, and policy to crop production. It will increase with the development of science and technology and the elapse of time. Meteorological yield has tended to decrease since 1950s. Without consideration to varieties and cropping system, meteorological yield would decrease 170.40, 134.25, 98.70 and 97.20 kg/hm$^2$ in the north China and 13.95, 7.95, 39.60 and 19.80 kg/hm$^2$ in the northwest China compared with that in 1950s, 1960s, 1970s and 1980s, respectively, when the $CO_2$ concentration in the atmosphere is doubled.

**Table 5 The change of winter wheat yield, kg/hm$^2$**

| Decades | North China | | | Northwest China | | |
|---|---|---|---|---|---|---|
| | $Y$ | $Yw$ | $Y_t$ | $Y$ | $Y_w$ | $Y_t$ |
| 1950s | 890.25 | 757.95 | 132.30 | 1121.10 | 1070.25 | 50.85 |
| 1960s | 934.80 | 838.80 | 96.15 | 1032.90 | 987.75 | 45.15 |
| 1970s | 1688.85 | 1628.25 | 60.60 | 1557.00 | 1480.50 | 76.50 |
| 1980s | 3079.20 | 3020.25 | 59.10 | 2287.20 | 2233.50 | 53.70 |
| $2\times CO_2$ | | | −38.10 | | | 36.90 |

*The impacts of climate change on dry weight of leaf and stalk and grain yield*

As shown in the experiments of sowing by stages in Yongning and Guyuan during 1989 to 1991, weight of leaf and stalk of spring wheat at main development stages tended to decrease with the increase of temperature. The experiment results of Yongning and Guyuan in 1990 is listed in Table 6 and Table 7, respectively.

**Table 6 Dry weight of leaf and stalk for spring wheat and meteorological condition in Yongning at main stages in 1990**

| Items | Jointing stage | | | | Booting stage | | | | Blooming | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A2 | A3 | A4 | A1 | A2 | A3 | A4 | A1 | A2 | A3 | A4 |
| Stalk, g | 0.147 | 0.102 | 0.107 | 0.091 | 0.563 | 0.624 | 0.514 | 0.413 | 0.976 | 1.014 | 0.802 | 0.840 |
| Leaf, g | 0.152 | 0.137 | 0.135 | 0.132 | 0.293 | 0.310 | 0.304 | 0.267 | 0.245 | 0.282 | 0.232 | 0.283 |
| *T*, ℃ | 13.7 | 16.1 | 16.4 | 16.8 | 16.8 | 16.5 | 17.4 | 18.8 | 19.0 | 20.0 | 20.5 | 21.3 |
| *R*, mm | 0.31 | 0.58 | 2.80 | 2.24 | 1.34 | 1.34 | 0.0 | 0.16 | 0.10 | 0.16 | 0.15 | 0.25 |

**Table 7 Dry weight of leaf and stalk for spring wheat and meteorological condition in Guyuan at main stages in 1990**

| Items | Jointing stage | | | | Booting stage | | | | Blooming | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A2 | A3 | A4 | A1 | A2 | A3 | A4 | A1 | A2 | A3 | A4 |
| Stalk, g | 0.157 | 0.162 | 0.103 | 0.087 | 0.540 | 0.613 | 0.447 | 0.300 | 0.787 | 0.760 | 0.540 | 0.617 |
| Leaf, g | 0.210 | 0.200 | 0.157 | 0.127 | 0.257 | 0.268 | 0.207 | 0.177 | 0.242 | 0.223 | 0.120 | 0.137 |
| *T*, ℃ | 13.4 | 13.1 | 14.7 | 17.1 | 15.8 | 15.9 | 17.5 | 17.7 | 17.0 | 17.6 | 18.7 | 18.2 |
| *R*, mm | 5.01 | 4.99 | 0.01 | 1.00 | 0.80 | 0.91 | 0.93 | 0.39 | 0.62 | 0.65 | 0.43 | 6.03 |

As shown in Table 6, dry weight of stalk and leaf of sowing time A1 at Yongning was 0.147 g and 0.152 g, respectively, at jointing stage when the mean daily temperature was 13.7 ℃, whereas the temperature was 16.1 ℃, 2.4 ℃ higher, at the same stage, the weight of A2 was 31% and 10% lower than that of A1 respectively. These differences between A1 and A2 were mainly due to shorter duration (17 days for A1 and 6 days for A2) from tillering to jointing stage and the faster development rate in sowing time A2 that was caused by higher temperature in A2. As a conclusion, the climate warming is unfavorable to the accumulation of above ground dry matter for spring wheat.

Precipitation has positive effect to the dry weight of leaf and stalk, it means that precipitation increase is favorable to the accumulation of the weight of leaf and stalk. This effect is more significant in rainfall maintained agriculture region. At blooming stage in Guyuan, for example, the mean daily precipitation in A3 and A4 was 0.43 and 6.03 mm, respectively (the difference was 5.6mm), and the temperature was 0.5℃ lower than that in A3. As a result, the weight of leaf and stalk increased about 14% than that in A3. This was mainly owing to the more precipitation.

*Impacts on spring wheat yield*

Production formation is directly restricted by meteorological condition. Precipitation and temperature are the guiding factors in drought and semi-drought region. Fig. 2 shows the relationships between the yield (in sowing time A1, A2, A3 and A4) and the meteorological conditions. From the figure it can be seen that the yield (*Y*) is tend to decrease with the sowing time postponement, that means that the yield will decrease with higher temperature. The difference of mean daily temperature was 4.85 ℃ between sowing time A1 and A4, that resulted a difference of 2232.0 kg/hm$^2$ in production. Taking that precipitation is constant, it can be recognized that the spring wheat yield will decrease by 450.0 kg/hm$^2$ when 1 ℃ rises in temperature.

The effect of precipitation on spring wheat yield is opposite to the temperature, that is to say, yield will decrease with the precipitation reducing. Providing a constant temperature, the yield would decrease about 45 kg/hm$^2$ when the precipitation decrease 1 mm. The same tendency exists in rainfall maintained agriculture region. According to the analysis with meteorology-yield models, the impacts of climate change on spring wheat yield in the northeast China are listed in Table 8.

As it is shown in Table 8 that the meteorological production of spring wheat tend to decrease with temperature rising and increase with temperature dropping. The main reason is that temperature rising will cause the development rate to be faster, development period to be shorter, especially, the durations from emergence to

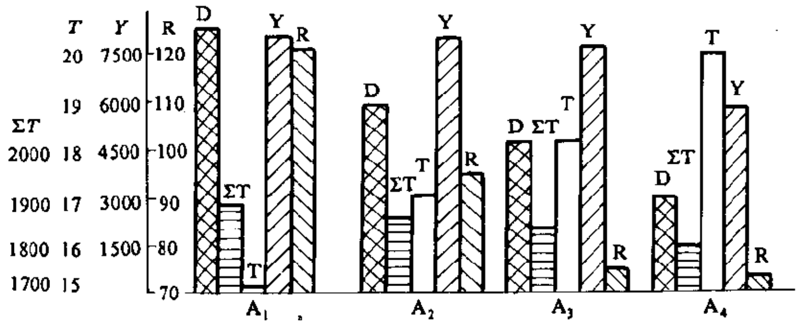


Fig. 2 The relationships between spring wheat production (*Y*) and meteorological situations (Yongning, 1990)

*y*— Yield; *D*— Growth period; $\sum T$—Accumulate temperature; *M*— Mean temperature; *R*— Precipitation; *A*— Sowing time

**Table 8 The impacts of climate change on meteorological yield (Relative to the mean tendency in 1980s)**

| *R*, % | *T*, ℃ | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3 | 2 | 1 | 0 | −1 | −2 | −3 |
| 30 | −4.93 | −3.44 | −1.50 | 1.22 | 4.68 | 8.46 | 12.35 |
| 20 | −5.25 | −3.91 | −1.97 | 0.84 | 4.21 | 8.06 | 11.95 |
| 10 | −5.72 | −4.36 | −2.32 | 0.37 | 3.82 | 7.66 | 11.54 |
| 0 | −6.20 | −4.85 | −2.80 | 0.00 | 3.44 | 7.19 | 11.37 |
| −10 | −6.67 | −5.20 | −3.16 | −0.37 | 3.06 | 6.80 | 10.66 |
| −20 | −7.00 | −5.67 | −3.63 | −0.84 | 2.59 | 6.40 | 10.26 |
| −30 | −7.48 | −6.02 | −3.99 | −1.31 | 2.20 | 6.01 | 9.85 |

jointing and from jointing to earing. As a result, the numbers of effective tillering would reduce and the ratio of fertilization would be lower; and the shorter duration of young ear differentiation is unfavorable to grow up great ears. On the contrary, temperature dropping would cause the development rate to be slower, the longer the period from emergence to jointing is, the higher the numbers of tillering increase and the ratio of their fertilization will be; and the lengthening in the period from jointing to earing and duration of young ear differentiation is favorable to grow up great ears. Therefore, the impacts of climate change responsible for yield variation of spring wheat are mainly on the change effective ears and the grain numbers on each ear.

The yield of spring wheat increase will with the precipitation enhancing and decrease with its reducing.

## CONCLUSION

As a summary of that mentioned above, both the growth and development and the ultimate production of wheat are closely related to climate change. Under the condition of present production level in China, agriculture is basically still in the stage of fed on heaven, that means climate is also one of the limiting factors to it. So, studies on the impacts of climate change on agriculture have profound economical, social, and ecological significance.

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