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Impacts of climate change on development rate and production of corn in the northeastern China

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Abstract— In this paper, the impacts of climate change on development rate and production of corn in the northeastern China are discussed. The results show that the higher the temperature is, the faster the development rate will be. And the more the precipitation is, the slower the development rate will be. Of which, air temperature is the controlling factor of corn development rate. The influences of development rate on corn yield are remarkable. The impacts of development rate on production in first and last periods are great, and small in the middle two periods. The development rate is positive by relate with corn production from sowing to emergence stage and negative during other periods. So, it is very important to arrange a suitable sowing time for corn cultivating in the northeastern China.

Keywords: climate change; development rate; corn.

INTRODUCTION

At the beginning of this century, the fossil fuel consumption increased and forest area decreased quickly with the development of industry and frequent human activities. It presents that the global atmospheric CO_2 contents and other trace gases successive increase, and then enhanced the global "Greenhouse Effect". Greenhouse effect has direct impact on growth and yield of corn, on that many studies and approaches have been done by scientists in many countries. The impacts of temperature rise on agricultural production were discussed by Waggoner, P. E. (Waggoner, 1983), Rosenberg, N. J. (Rosenberg, 1981; 1982), and Idso, S. B. (Idso, 1983). Zhang Jiacheng (Zhang, 1982) studied in China that the total grain yield would increase about 10% providing 1 ℃ and 100 mm rise in annual mean temperature and total precipitation, and the heat condition difference would directly influence the selection of crop and varieties system. The impacts of greenhouse effect on grain yield and cultivating system in China were studied by Gao Suhua (Gao, 1990). Impacts of air temperature change on agricultural production and countermeasures in Dabeixiang of Tianjin was analyzed by Guo Jianping (Guo, 1990). Whereas few studies have been presented for the impact of climate change on crop development rate. Weather mathematic models based on many temperature factors to estimate crop development rate were proposed by Jodge (Jodge, 1984). Guo Jianping (Guo, 1991) developed a model to asses the impacts of climate change on winter wheat development rate in the north China. And Pan Yaru (Pan, 1991) proposed a model for estimating impacts of climate change on development rate for spring wheat in the northeastern China. In this paper, the authors attempt to establish a relationship of corn development rate with climate factors and the rate with its production in the northeastern China to assess the impacts of climate change on corn development rate and production in this area.

DATA AND METHOD

Data

The data, including the stages of corn growth and development and meteorological records from 1981 to 1989, are collected from 8 weather stations: Chifeng, Kuandian, Fuyu, Bayan, Boli, Benxi, Suizhong, and Dunhua. The total samples are 72.

Method

Because of the great difference of meteorological conditions and corn varieties planted in the stations above, duration for the same growth stage varies considerably in different stations, following method has been adopted.

(1) Duration between two development stages was normalized; and the development rate (V) is the reciprocal of it:

$$V = D_m / D, \quad (1)$$

where D and D_m are the measured duration and the longest duration in each station. V is called development rate. It is clear from Equation (1) that the smallest value of V is 1.

(2) Statistical models relating V to meteorological factors in the corresponding duration were established to analyze the impacts of climate change on corn development rate.

MODELS SIMULATING THE RELATIONS BETWEEN CLIMATE FACTORS AND DEVELOPMENT RATE

There are many successive stages in the whole life of corn. The time between two closing stages is called development duration. The days and influential factors and their strength and pattern in each duration were different between stages that suggests us to divide the whole life of corn into several development periods in order to analyze the impacts of climate change on its development rate more clearly: sowing-emergence, emergence-jointing, jointing-earing, earing-maturity. Models for each period are listed in Table 1. It is clear from the table that the development rate of former 3 periods was positively related to mean temperature and negatively to precipitation. That is to say that the higher the temperature is, the faster the development will be, and the more the precipitation is, the slower the development will be, and vice versa. In addition, the relationship between development rate and combined value of temperature and precipitation showed an exponential function. The development rate from earing to maturity was parabolically related only with temperature.

Table 1 The relationship between development rate and meteorological factors

Development stage	Models	F
Sowing-emergence	$V=0.5767\ \exp(0.0624T-0.0017R)$	23.1397**
Emergence-jointing	$V=0.7722\ \exp(0.0248T-0.0004R)$	5.7646**
Jointing-earing	$V=1.0118\ \exp(0.0142T-0.0005R)$	3.1745*
Earing-maturity	$V=0.9049+0.0005T$	8.8982**

* Means the significant level is 0.05; ** Means the significant level is 0.01

IMPACTS OF CLIMATE CHANGE ON CORN DEVELOPMENT

The impacts of climate change on corn development at each stage can be assessed with the models listed in Table 2 in the case of ±1, ±2 and ±3 ℃ variations in temperature and ±10%, ±20% and ±30% in precipitation.

Sowing-emergence

The impacts of climate change on development rate from sowing to emergence are shown in Table 2. As shown in the table, the higher the temperature is, the faster the development rate will be, and the more the precipitation is, the lower the development rate will be. Taking precipitation as a constant, temperature changes of −3, −2, −1, 0, +1, +2, and +3 ℃ would correspond of the rates 1.2274, 1.3064, 1.3906, 1.4801, 1.5754, 1.6768 and 1.7848. The difference of rate between the case of −3 ℃ and +3 ℃ was 0.5574 that means that the average variation of development rate providing 1 ℃ change in temperature was 0.0929. Under the condition of a constant temperature, development rate would be 1.4995, 1.4930, 1.4865, 1.4801, 1.4737, 1.4673 and 1.4610, respectively, in the cases of −30%, −20%,

−10%, 0%, +10%, +20%, and +30% changes in precipitation. Difference of the rate between the case of −30% and +30% was 0.0385 that suggests an average variation of development rate of 0.0064 by the change of every 10% in precipitation.

Table 2 Development rates under different climate conditions from sowing to emergence

ΔR, %	ΔT, ℃						
	−3	−2	−1	0	+1	+2	+3
−30	1.2435	1.3235	1.4088	1.4995	1.5960	1.6988	1.8082
−20	1.2381	1.3178	1.4027	1.4930	1.5891	1.6941	1.8003
−10	1.2327	1.3121	1.3966	1.4865	1.5822	1.6841	1.7926
0	1.2274	1.3064	1.3906	1.4801	1.5754	1.6768	1.7848
+10	1.2221	1.3008	1.3846	1.4737	1.5686	1.6696	1.7771
+20	1.2168	1.2952	1.3785	1.4673	1.5618	1.6624	1.7694
+30	1.2115	1.2895	1.3726	1.4610	1.5550	1.6552	1.7617

Emergence-jointing

Development rate from emergence to jointing was related with precipitation and temperature, and latter was the main climate factor impacting the rate. The development rates from emergence to jointing under different climate condition are shown in Table 3. It is clear from the table that the higher the temperature is, the faster the rate will be, and the more the precipitation is, the slower the rate will be. Providing precipitation to be constant, temperature change of −3 ℃ and +3 ℃ would correspond the development rate of 1.0828 and 1.2565, the variation range was 0.1637. For 1 ℃ change in temperature, the variation of rate was 0.0273 in average. If temperature do not change, the variation of −30% and +30% in precipitation would make the rate change from 1.1845 to 1.1486 of that 0.0359 was the variation range. Taking this for granted, the variation of the rate might be 0.0060 in average for the change of each 10% in precipitation.

Jointing-earing

Close relationship exists between the development rate from jointing to earing stage and temperature and precipitation. In general, the higher the temperature is, the faster the rate will be, the more the precipitation is, the slower the development will be, and vice versa (Table 4). If temperature do not change, change of −30% and +30% in precipitation would make development rate be 1.3259 to 1.2790 with a variation range of 0.0469. If so, for each 10% change in precipitation 0.0078 would be the change of development rate in average. Supposing that precipitation do not change, the general variation of development rate would be 0.0185 for each 1 ℃

change in temperature.

Table 3 Development rates under different climate conditions from emergence to jointing

ΔR, %	ΔT, ℃						
	−3	−2	−1	0	+1	+2	+3
−30	1.0996	1.1272	1.1555	1.1845	1.2142	1.2447	1.2760
−20	1.0939	1.1214	1.1496	1.1784	1.2080	1.2384	1.2695
−10	1.0883	1.1157	1.1437	1.1724	1.2018	1.2320	1.2630
0	1.0828	1.1100	1.1378	1.1664	1.1957	1.2257	1.2565
+10	1.0772	1.1043	1.1320	1.1604	1.1896	1.2194	1.2501
+20	1.0717	1.0986	1.1262	1.1545	1.1835	1.2132	1.2437
+30	1.0662	1.0930	1.1205	1.1486	1.1774	1.2070	1.2373

Table 4 Development rates under different climate conditions from jointing to earing stage

ΔR, %	ΔT, ℃						
	−3	−2	−1	0	+1	+2	+3
−30	1.2706	1.2888	1.3072	1.3259	1.3449	1.3641	1.3836
−20	1.2630	1.2811	1.2994	1.3180	1.3368	1.3559	1.3753
−10	1.2554	1.2734	1.2916	1.3101	1.3288	1.3478	1.3671
0	1.2479	1.2658	1.2839	1.3022	1.3209	1.3398	1.3589
+10	1.2405	1.2582	1.2762	1.2945	1.3130	1.3317	1.3508
+20	1.2330	1.2507	1.2686	1.2867	1.3051	1.3238	1.3427
+30	1.2257	1.2432	1.2810	1.2790	1.2973	1.3159	1.3347

Earing-maturity

The stage from earing to maturity is the key period for corn to produce high yield. Meteorological condition during this period plays a decisive role in fertilizing and milking of grains. The development rates of this period under different climate conditions are shown in Fig. 1. It only shows the relationship between the development rate and temperature, but this do not mean that there was not any relation between rainfall and the rate. Instead of that, the relation was not yet statisti-

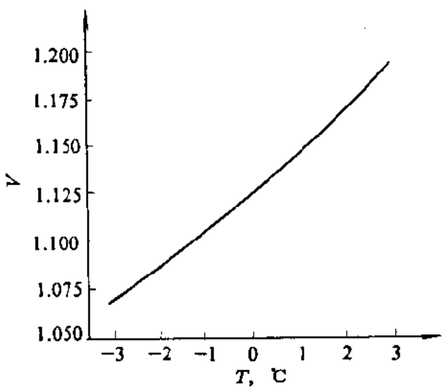

Fig. 1 The development rates under different climate conditions from earing to maturity stage

cally significant as the precipitation was enough to meet the less requirement in water for corn growth during its later growth period. In general, devleopment rate change would be 0.0209 under the variation of 1 ℃ in mean temperature.

RELATIONSHIPS BETWEEN DEVELOPMENT RATE AND PRODUCTION

The ultimate aim of analyzing the impacts of climate change on development rate is to study its effects on crop production. For that the multiple regression models relating the development rate with corn production were established, that is

$$Y=6231.60+3364.35V_1-575.85V_2-455.25V_3-2862.60V_4$$

$$r=0.9194^{***}, \quad (2)$$

where Y is the real production; V_1, V_2, V_3, and V_4 are development rate from sowing to emergence, from emergence to jointing, from jointing to earing, from earing to maturity, respectively.

Equation (2) shows that the positive relationship existed between the production and the development rate from the sowing to emergence stage. The contribution of the increase of every 0.1 in the rate (equals to about 1.1 days shorter of the duration than that in 1980s in Benxi, 1.2 days shorter in Kuandian) to the corn production was 336.44 kg/hm^2. The reason is that faster development rate, higher temperature and more rapid water absorption are favorable to seed germination. Consequently, seedling was emerged uniformly and grew strongly. This formed the material foundation for the growth of the following stages and for producing high production. Faster development rate from emergence to jointing stage was unfavorable to yield formation as it would shorten the duration, and effect the growth of root, stalk, and leaf, the expansion of the growth cone of male ear, and the differentiation of reproduction organ. For example, 0.1 increase in the development rate (equals to about 3.3 days shorter of duration than that in 1980s in Benxi, or 4.2 days in Kuandian) would lead 57.60 kg/hm^2 decrease in production of corn, in contrast, 0.1 decrease in development rate would lead 57.60 kg/hm^2 increase in production. Production was negatively related with the development rate from the jointing to earing stage, in general, 0.1 increase in the development rate (equals to 1.9 days shorter of duration than that in 1980s in Benxi, or 1.7 days in Kuandian) would 45.50 kg/hm^2 decrease in bring out corn production, or the development rate decrease by 0.1 would correspond the corn yield increase by 45.50 kg/hm^2. This was because that the slower the development rate is, the longer the growth and ear differentiation duration will be, and the more the number of spikelet and young flowers will be. This would benefit to the formation of great ear with more grain, and the ratio of empty spilkelet and blighted grains would also be reduced. The growth stage from earing to maturity is the period during which tasseled flowers scatter their pollen, the silk of ears expand and is fertilized, and grains are milked, therefore, lower development rate will prolong the duration for the tasseled flowers to meet the silk of ears for full fertilization, consequently, the ratio of bald cone of the ear will be decreased, the duration of grain milking prolonged, and the weight of hundred-grain increased. So, the influence of the development rate during this period on production is great. It is clear from Equation (2) that the development rate was negative related with the corn production during this period. In general, 0.1 increase in development rate (equals to the about 4.4 days shorter in duration than that in 1980s in Benxi, or 4.2 days in Kuandian) would result 286.26 kg/hm^2 decrease in corn prodution, and vice versa.

From that explained above, we can conclude that influence of development rate on production was considerable. The development rate was positive by related with crop production from sowing to emergence stage. Duration other stages they were negatively related. The tendency reflected from the models showed a good agreement with the physiological activities of the plant and the course of production formation. The impacts of development rate on production in the first and last periods were great, and small in the middle two periods. Therefore, it is very important to arrange a suitable sowing time in corn cultivating.

CONCLUSION

1. The impacts of climate change on corn development rate are considerable in the northeastern China. The higher the air temperature is, the faster the development rate will be. And the more the precipitation is, the slower the development rate will be. Of which, air temperature is the controlling factor for corn development rate.

2. The influences of development rate on corn yield are remarkable. Faster development rate in the period from sowing to emergence is favorable to increasing corn yield, and in the other periods, the situation is the opposite. The impacts of development rate on production in first and last period are great, and small in the middle two periods.

3. It is very important to arrange a suitable sowing time for corn cultivating in the northeastern China.

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