



Study on the Variation of Climate Suitability of Potato in Different Growth Periods——Taking Wuchuan County, Hohhot City as an Example

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Abstract: Using daily meteorological elements and statistical methods, a climate suitability evaluation model for potato in each growth period was established, and the temperature, precipitation, sunshine, and climate suitability values of potato in each growth period from 1983 to 2014 in Wuchuan County, Inner Mongolia were calculated. The characteristics and changing trend of climatic suitability during the growth period were analyzed. The results showed that the temperature suitability was the highest during the potato growing period, followed by sunshine, the lowest precipitation and the largest variation coefficient. The temperature suitability was the lowest in the flowering-harvest period, and the coefficient of variation was the largest; the precipitation suitability was the lowest in the inflorescence-flowering period, and the coefficient of variation was the largest; the sunshine suitability was the lowest in the branch-inflorescence period, and the coefficient of variation was the largest. The variation trend of suitability for many years is as follows: the suitability of temperature in the whole growth period is basically the same; the suitability of sunshine peaked in 2001, and then decreased significantly; the suitability of precipitation peaked in 1998, then fluctuated and decreased, and has shown a rising trend in the past two years. The change trend of climatic suitability is basically similar to that of precipitation suitability, but the variation range is smaller than that of precipitation suitability, and the change trend of precipitation suitability dominates the change trend of climate suitability. The climatic suitability of each growth period (except the sowing-emergence period) showed an obvious decline process after 2000, reaching the lowest value in 2011/2012, and there has also been a clear upward trend in the past two years. The negative effect of climate change on potato growth in Wuchuan County will be reduced or changed in the future. However, the change of sunshine suitability is different, and it is still in a downward trend in the past two years, which should be paid attention to.

Keywords: Wuchuan County, Potato Suitability, Growth Period

1. Introduction

The climate change since the 1990s has had a great impact on agriculture. Under the background of global climate change, it is of great significance to study the changes in the climatic suitability of crop growth for guiding agricultural production.

At present, the evaluation of the suitability of climatic resources for crop growth has gradually shifted from qualitative to quantitative [1-8]. Relevant scholars have analyzed and studied the suitability evaluation model of meteorological conditions based on the actual local conditions, and established different A model for evaluating the climatic suitability of different crops in the region [9-12]. Research on climate suitability in Inner Mongolia has also

made some progress recently [13]. For example, Sun Xiaolong et al. [13] established a simulation model of maize growth period in Hetao irrigated area based on climatic suitability, which was used to predict the growth period and yield of maize in Hetao area. [14] established a corn climate suitability evaluation model in southeastern Inner Mongolia, and analyzed the characteristics of climate suitability in the past two years. The Inner Mongolia Autonomous Region has also done a lot of work on the impact of potato climate [15-17], and has carried out research on the climatic zoning of potato production, and put forward corresponding suggestions for the study area. Jin Linxue [18] analyzed the climatic suitability of potato in the key growth period of Inner Mongolia. However, there are few reports on the climatic suitability characteristics and changing trend of potato in each growth period. Potato is one of the main food crops in Inner Mongolia. Its production status to a large extent, it affects the food security and social stability of Inner Mongolia. Based on the previous research results, this paper uses the improved climate suitability evaluation model to comprehensively analyze the characteristics of the climatic suitability and its changing trend in each growth period of potato in Inner Mongolia, and explore the relationship between the changes of climatic factors and potato production. It is beneficial to grasp the critical period of climate that affects potato production, so as to provide decision-making basis for potato production management to adapt to climate change. Therefore, it is of great theoretical and practical significance to study the changes in the climatic suitability of potato in each growth period.

2. Materials and Methods

2.1. Data Sources

In order to quantitatively evaluate the change of potato climate suitability in Wuchuan County, the daily precipitation, temperature and sunshine hours data of Wuchuan County

Meteorological Station from 1983 to 2014 were selected, and the data came from the Inner Mongolia Climate Center. The data of potato yield per unit area in Wuchuan County from 1983 to 2014 were taken from Hohhot Statistical Yearbook.

2.2. Stablistment of Potato Climate Suitability Model

2.2.1. Temperature Suitability Function

In order to quantitatively analyze the satisfaction degree of heat resources in Inner Mongolia for the growth and development of potato in each growth period, the response function of potato growth to temperature conditions was introduced. According to Ma Shuqing's research [1], the temperature suitability can be calculated by the following formula:

$$F_i(i) = [(T - T_1)(T_2 - T)^B] / [(T_0 - T_1)(T_2 - T_0)^B] \quad (1)$$

$$B = (T_2 - T_0) / (T_0 - T_1) \quad (2)$$

In the formula, $F_i(i)$ is the temperature suitability evaluation index of the i -th growth period. In the formula: T is the average temperature of a certain growth period, T_1 , T_2 , T_0 are the lower limit temperature, upper limit temperature and optimum temperature of potato growth and development in this period respectively (Table 1), $F_i(i)$ is the actual temperature Potato temperature suitability determined by T and T_1 , T_2 and T_0 . According to the relationship between potato growth and temperature, when $T < T_1$, $F_i(i) = 0$; when $T = T_0$, $F_i(i) = 1$; when $T > T_2$, $F_i(i) = 0$. It can be seen that $F_i(i)$ is an asymmetric parabolic function that varies between 0 and 1, and is actually a fuzzy membership function, which reflects the continuous changing process of temperature conditions from unsuitable to suitable to unsuitable. This function reflects a general law, that is, crop yield increases with the increase of temperature, and after reaching a certain suitable value, the yield decreases rapidly with the increase of temperature.

Table 1. T_0 , T_1 and T_2 values during every growth stage of potato in Wuchuan County.

Growth period	Sowing-emergence	Emergence-branch	Branch-inflorescence	Inflorescence-blooming	blooming-harvest	full reproductive period
T_1	5	9	10	10	10	5
T_2	29	32	30	30	29	32
T_0	14	18.3	19.5	19.3	18	17.8

Note: The data in the table are compiled and analyzed according to the literature research results and the local meteorological bureau's agricultural meteorological observation data over the years.

In this paper, the weighted average of temperature suitability changes with time in the whole growth period is called the temperature suitability of the whole growth period, denoted as, and its weight is expressed as, then the temperature suitability of the potato throughout the growth period can be expressed as:

$$F_i = \sum_{i=0}^n b(i)F_i(i) \quad i \in [0, n] \quad (3)$$

In the formula, $F_i(i)$ is the temperature suitability evaluation index of the i th growth period, and n is the number of growth periods.

2.2.2. Precipitation Suitability Function

According to the graph of the relationship between crop yield and precipitation by Xu Xuexuan et al. [2], the water requirement for normal growth of potatoes in Wuchuan County, Hohhot City, Inner Mongolia is taken as the appropriate water requirement standard for potatoes (Table 2). Spend:

$$F_p(i) = \begin{cases} 1 & P \geq W \\ P/W & P < W \end{cases} \quad (4)$$

In the formula, $F_p(i)$ is the water suitability evaluation index of the i -th growth period, and the index value ranges

from 0 to 1, P is the precipitation at different growth stages, and W is the physiological water requirement of crops at different growth stages. When P is slightly larger than W and can be completely absorbed by soil storage, it can be considered that $F_p \approx 1$.

Table 2. Physiological water demand of potato during every growth period in Wuchuan County.

Growth period	Sowing-emergence	Emergence-branch	Branch-inflorescence	Inflorescence-blooming	blooming-harvest	full reproductive period
W (mm)	50	40	30	52.5	200	372.5

Note: The data in the table are obtained from the research results of the literature [12, 13] and the local meteorological bureau's agricultural meteorological observation data over the years.

In this paper, the weighted average of the variation of precipitation suitability over time in the whole growth period is called the precipitation suitability of the whole growth period, denoted as, and its weight is expressed as, then the precipitation suitability of the potato throughout the growth period can be expressed as:

$$F_p = \sum_{i=0}^n b(i)F_p(i) \quad i \in [0, n] \quad (5)$$

In the formula, $F_p(i)$ is the precipitation suitability evaluation index of the i -th growth period, and n is the number of growth periods.

2.2.3. Sunshine Hours Suitability Function

Like temperature and precipitation, the effect of light conditions on crop growth can also be understood as a fuzzy

process that is, changing between "suitable and unsuitable". In this paper, the critical point is that the sunshine hours reach 70% of the available sunshine hours (sunshine percentage) [3], and it is believed that when the sunshine percentage reaches more than 70%, the response of potatoes to light conditions will reach an appropriate state (the response process of potato sunshine is shown in Figure 3. The membership function form of sunshine hours is:

$$F_s(i) = \begin{cases} 1 & S \geq S_0 \\ S/S_0 & S < S_0 \end{cases} \quad (6)$$

In the formula: S represents the actual sunshine hours (h), and S_0 represents the sunshine hours with a sunshine percentage of 70%. See Table 3 for S_0 values.

Table 3. S_0 value of potato at different growth period.

Growth period	Sowing-emergence	Emergence-branch	Branch-inflorescence	Inflorescence-blooming	full reproductive period
S_0	10.4	10.5	10.5	10.3	10.0

In this paper, the weighted average of the suitability of sunshine hours over time in the whole growth period is called the suitability of sunshine hours in the whole growth period, denoted as, and its weight is expressed as:

$$F_s = \sum_{i=0}^n b(i)F_s(i) \quad i \in [0, n] \quad (7)$$

In the formula, $F_s(i)$ is the sunshine hours suitability evaluation index of the i -th growth period, and n is the number of growth periods.

2.2.4. Climate Suitability Model

The relationship between the growth and development of potato and the formation of final yield and the ecological environment conditions is intricate and is most affected by the combination of ecological environment factors. The positive effect of one factor or several factors on potato growth may be strengthened by other factors, may also be attenuated, or even completely canceled. The establishment of the above potato temperature, precipitation and sunshine suitability functions has its premise and assumptions. That is, other environmental factors except its own (temperature,

precipitation or sunshine) are suitable for the growth and development of potato. This is an ideal scientific hypothesis, which can only reflect the influence of a single factor, and it is difficult to express the synergistic effect of multiple factors. In order to comprehensively reflect the influence of the three factors on the suitability of potato, reasonably evaluate the suitability of potato to the possible climate resources and its response to global warming since the 1980s, a potato climate suitability dynamic model was established:

$$F_i = a \times F_t + b \times F_p + c \times F_s \quad (8)$$

In the formula, a , b , c respectively represent the weight coefficients of temperature, precipitation and light suitability during the whole growth period of potato. Through the analysis of the correlation between the climate suitability evaluation value and the meteorological yield of potato, it is found that the correlation between the two has reached a very significant level, the results show that the climate suitability model of potato designed in this paper can objectively reflect the climate suitability level and dynamic change of potato in Wuchuan County, Inner Mongolia.

2.2.5. Determination of Weight Coefficient

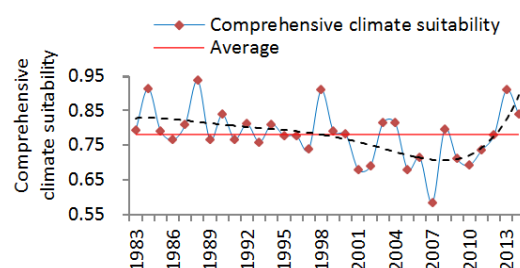
Due to the different ecological and physiological characteristics of crops in different growth periods, their demands on the surrounding environmental conditions are different. At the same time, the degree of satisfaction of environmental ecological factors for crop growth and yield formation in different periods also differed significantly. Therefore, in order to objectively reflect the influence intensity of ecological factors on crops in different periods, to calculate the suitability of temperature, light and precipitation in each growth period or the whole growth period, it is necessary to first set the weight for the suitability index of each growth period. In this paper, the correlation coefficient method is used to determine the weight coefficients. Firstly, the potato yield was separated into meteorological yield by orthogonal polynomial method, and the correlation coefficient between sunshine, temperature, precipitation suitability and meteorological yield in each growth period of potato was calculated; then the correlation coefficient was normalized to eliminate the positive and negative signs, and the magnitude and direction order of the values remain unchanged. Then calculate the contribution rate of the suitability of each climatic element to meteorological yield, and the normalized value of the contribution rate of the three elements in the same developmental period is used as the weight coefficient of the climatic suitability of the three elements in this developmental period; the same is the contribution of the climatic suitability of each developmental period to the meteorological yield. The normalized value of the rate is used as the weight coefficient of the climatic suitability of this developmental period to the whole growth period.

3. Results and Analysis

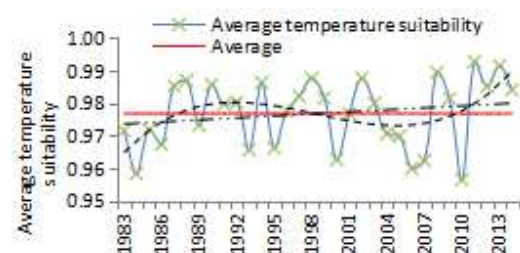
3.1. Interannual Variation of Climate Suitability in the Whole Growth Period

The average temperatures, precipitation, light and comprehensive climate suitability of potato in Wuchuan County were all above 0.65. Among them, the temperature suitability was the largest, with an average value of 0.9768. In the 30 years from 1983 to 2012, the minimum value in 2010 was 0.9565, the maximum value was 0.9927, which appeared in 2011; the second was sunshine suitability, with an average value of 0.7785. In 30 years, the minimum value was 0.5636 in 2007, and the maximum value was 0.8599, which appeared in 1991; the minimum was precipitation Suitability, the average value is 0.6540, and the fluctuation of precipitation suitability is the largest. In 30 years, the minimum value was 0.3474 in 2007, and the maximum value was 0.9558, which appeared in 1988. In recent years, the temperature, precipitation and comprehensive climate suitability have all increased, and the change trends are relatively consistent. They all appeared in a trough in 2007, and then fluctuated and increased, and they have been in the high-value area in recent years. The light suitability is different, which is decreasing year by year in a fluctuating manner, and has been in a low value area in recent years (Figure 1). It can be seen from the cumulative anomaly curve of climate suitability in the whole growth period of potato in Wuchuan County (Figure 2) that the suitability

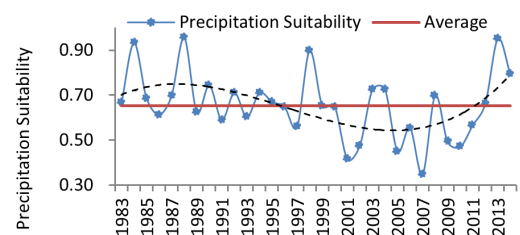
changes of temperature relative to precipitation and light are very gentle, and the change range is only within the range of plus or minus 0.1; the suitability of sunshine After reaching the peak in 2001, it turned to a decreasing trend, and it is currently in the low-value area; the precipitation suitability fluctuated the most. The change of precipitation suitability is basically similar, but the change amplitude is smaller than that of precipitation suitability. Therefore, it can be seen that the change trend of precipitation suitability dominates the change trend of climate suitability. In recent years, under the background of global warming, the trend of decreasing sunshine suitability in Wuchuan County is further increasing the negative effect on potato growth and development, which increases the risk of potato production in this area to a certain extent.



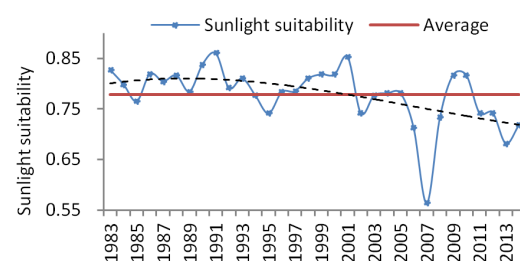
(a) The comprehensive climate suitability



(b) The change of Average temperature suitability



(c) The Changes of Precipitation Suitability



(d) The changes of Sunlight suitability

Figure 1. The interannual variation of the suitability of the main climatic factors in the whole growth period of potato in Wuchuan County (a Comprehensive climate suitability; b Average temperature suitability; c Precipitation Suitability; d Sunlight suitability).

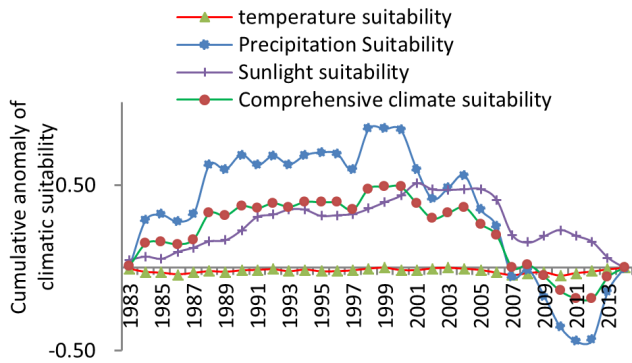


Figure 2. Cumulative anomaly of climatic suitability of potato throughout the growth period in Wuchuan County.

3.2. Interannual Variation of Climatic Suitability of Potato in Different Growth Stages in Wuchuan County

3.2.1. Interannual Variation of Temperature Suitability

It can be seen from the cumulative anomaly curve of temperature suitability in each growth period of potato in Wuchuan County (Figure 3) that the temperature in each growth period is relatively suitable, especially in the first three development periods, the suitability in most years is in the high value area; inflorescence—The suitability of the flowering period showed a downward trend after 2000, but it turned to an upward trend after 2010; the temperature suitability of the flowering-harvest period was the lowest, the coefficient of variation was the largest, and the cumulative anomaly was only negative in 2013 and 2014. Positive, indicating that the temperature suitability in this developmental period before 2013 was low, and there is currently an increasing trend. This shows that the increase in global temperature in recent years makes the temperature suitability of potato in Wuchuan County tend to increase during the flowering-harvest period, which is beneficial to the later growth and development of potato.

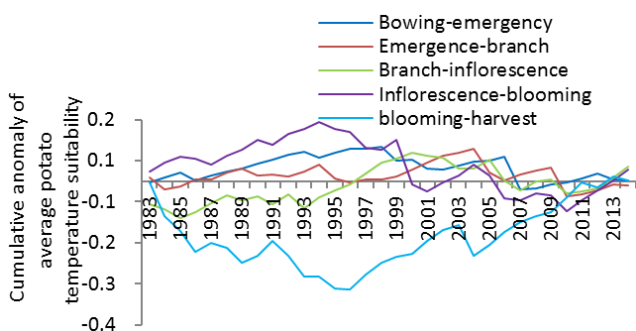


Figure 3. Cumulative anomaly of average potato temperature suitability in Wuchuan County.

3.2.2. Interannual Variation of Precipitation Suitability

According to the variation characteristics of the precipitation cumulative anomaly curve (Figure 4), the precipitation suitability was the lowest in the inflorescence-flowering period and the coefficient of variation was the largest. Potatoes have the most serious water shortage before and after emergence. Especially since 1995, the

average cumulative distance between sowing-emergence and emergence-branching in most years is negative. In the sharp decline, the cumulative anomaly of precipitation suitability in each growth period dropped to the lowest value by 2011, and has been on the rise again in the past two years. This shows that the suitability of precipitation in each growth period is gradually recovering, but precipitation deficit is still the main climatic factor restricting potato production.

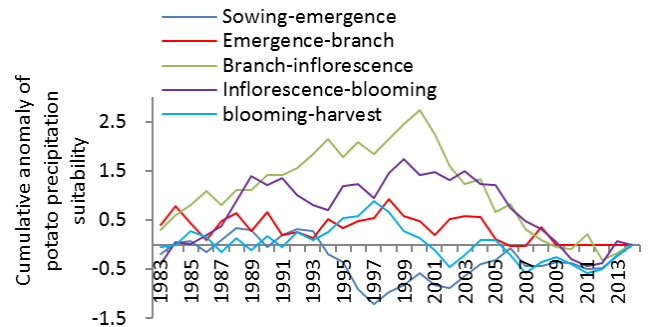


Figure 4. Cumulative anomaly of potato precipitation suitability in Wuchuan County.

3.2.3. Interannual Variation of Light Suitability

The interannual variation of light suitability in different growth stages was similar. The sunshine suitability was the lowest at the branch-inflorescence stage and the coefficient of variation was the largest. It can be seen from Figure 5 that the light suitability of each growth period is positive in most years, and there is a trend of first increase and then decrease in most development periods. Especially in recent years, the cumulative anomaly of light suitability in each growth period has entered the low-value area, and its change is still in a downward trend. This further shows that the decreasing trend of sunshine suitability in Wuchuan County in recent years will continue to increase the negative effect on the growth and development of local potatoes.

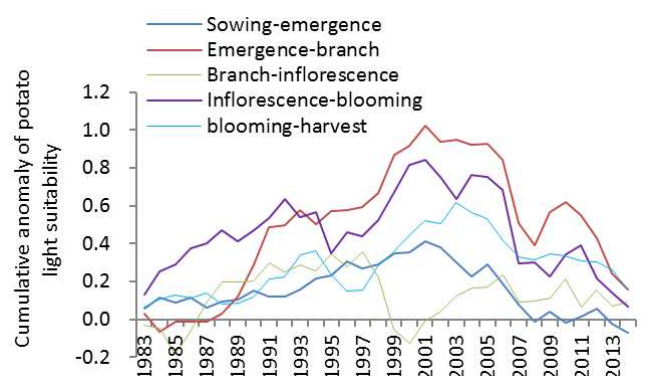


Figure 5. Cumulative anomaly of potato light suitability in Wuchuan County.

3.2.4. Interannual Variation of Climate Suitability

The change of the comprehensive climate suitability of light, temperature and water in each growth period of potato in Wuchuan County was similar to the change trend of the suitability of precipitation. It can be seen from Figure 6 that since 1995, the cumulative anomaly of climatic suitability in

most years at the sowing-emergence stage has been negative. The cumulative anomaly of climatic suitability during the 2011-2012 period also fluctuated and declined. From 2011 to 2012, the cumulative anomaly of climatic suitability in each growth period dropped to the lowest value., the cumulative anomaly of each growth period returned to around 0. It can be seen that the climatic suitability of potatoes in Wuchuan County has gradually recovered in the past two years, and these trend changes are beneficial to the future growth and development of potatoes.

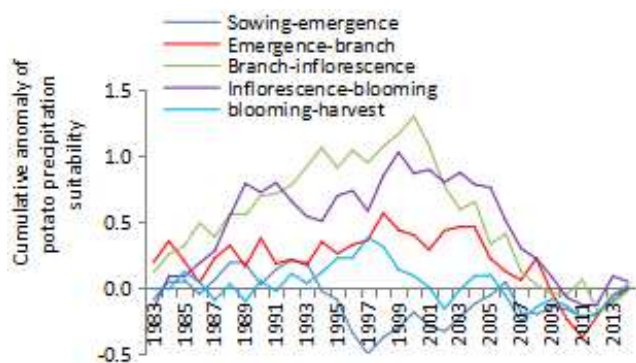


Figure 6. Cumulative anomaly of potato climatic suitability in Wuchuan County.

4. Conclusion

- (1) According to the agro-climatic conditions of Wuchuan County and referring to the previous research results, this paper establishes a potato climate suitability model. Through testing, it is found that this model can more objectively reflect the climatic suitability level of potato and its dynamic changes, and can provide theoretical support for the adjustment of agricultural policies and farming systems.
- (2) Using the established potato climate suitability model to calculate the precipitation, sunshine and temperature data in Wuchuan County, the results show that the temperature suitability of potato in Wuchuan County changes gently during the whole growth period, while the precipitation and sunshine suitability all show a rise first. In the past two years, the precipitation suitability has shown a rising trend, and the sunshine has maintained a downward trend. The fluctuation of temperature suitability is the smallest, followed by sunshine, and the strongest fluctuation of precipitation. Therefore, drought may still be the main stress factor for potato growth and development in Wuchuan County in the future. This conclusion is consistent with the research of Tang Jianzhao and others [18].
- (3) The temperature, precipitation, light and climate suitability of potato in different growth stages in Wuchuan County show different interannual variation characteristics. In recent years, global warming has made the growth stage of potato in Wuchuan County especially in the middle and late growth stages (flowering-harvest period). the temperature suitability

also tends to increase, which will be beneficial to the later growth and development of potato. This conclusion is consistent with the research of Zhao Junfang et Al. [19]. After more than ten years of decline, the suitability of precipitation reached the lowest value in 2011, and then turned to the rising stage. At present, the suitability of the sowing-emergence stage, inflorescence-flowering stage, and flowering-harvest stage have all turned positive. The rest of the developmental period is close to positive. Since 2000, the change of light suitability in each growth period has been on a downward trend, and it has not rebounded in the past two years, which should be paid attention to. The climatic suitability of the potato in Wuchuan County also showed a significant downward trend in all growth stages (emergence-branching, branching-inflorescence, inflorescence-flowering, flowering-harvest period), but in the past two years it showed a significant trend of decline. The uptrend is very noteworthy. Therefore, in production, corresponding agricultural measures must be adjusted according to the climatic suitability of the specific developmental stage of potato.

- (4) The establishment of potato climate suitability model provides an important index and technical method for studying the impact of climate and climate change on potato production. In 2019, I took potato climate suitability as a key climate sensitivity index; the impacts of Climate Change Vulnerability on potato industry in Inner Mongolia were discussed [20]. This is of great practical significance to further study the impact of climate change on potato.

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References

- [1] Ma, S. Agroclimate Research in Jilin Province [M]. Beijing: Meteorological Press, 1994: 33.
- [2] Xu, X. X.; Gao, P.; Jiang, Ding. S. Fuzzy analysis on the suitability of crop growth by precipitation in Yan'an [J]. Research on Soil and Water Conservation, 2000, 7 (2): 73-76.
- [3] Huang, H. Study on the climatic and ecological adaptability of crop production in the red and yellow soil regions of China [J]. Journal of Natural Resources, 1996, 11 (4): 341-345.
- [4] Bai, Y. P. Quantification and Evaluation of Agro-ecological Climate Resources in Northwest China (Ganning, Ningxia, Qinghai) [J]. Journal of Natural Resources, 2000, 15 (3): 218-224.
- [5] Zhao, F.; Qian, H. S.; Jiao, S. X. Research on crop climatic suitability model—taking winter wheat in Henan Province as an example [J]. Resources Science, 2003, 25 (6): 77-82.

- [6] Luo, H. L.; Chen, G. J.; Zhu, Bo. Research progress on agro-ecological climate suitability [J]. China Agricultural Resources and Zoning, 2004, 25 (1): 28-32.
- [7] Zhao, Feng.; Qian, H. S. Research progress on crop climatic suitability under the influence of global warming [J]. Chinese Journal of Ecological Agriculture, 2004, 12 (2): 134-137.
- [8] Luo, HL.; Chen, G. J.; Zhu, Bo. Research progress on agro-ecological climate suitability [J]. China Agricultural Resources and Zoning. 2004 (1).
- [9] Yao, S. R.; Wang, X.; Li, E. J. Analysis of cotton climate suitability and its temporal and spatial trend in Hebei Province [J]. Agricultural Research in Arid Areas, 2009, 27 (5): 4-29.
- [10] Ren, Y. Y.; Qian, H. S.; Liu, Q. Q. Analysis of Cotton climate suitability in Henan Province [J]. Agricultural Modernization Research, 2004, 25 (3): 231-235.
- [11] Liu, Qi. C.; Qian, H. S.; Ren, Y. Y. Analysis of temperature suitability and variation trend of cotton in Henan Province [J]. Resources Science, 2004, 26 (4): 51-56.
- [12] Qian, H. S.; Jiao, S. X.; Zhao, F. Study on climatic suitability changes of winter wheat in Henan Province [J]. Journal of Ecology, 2005, 24 (5): 503-507.
- [13] Sun, X. L.; Yan, W. X.; Wu, R. S.. Establishment of a simulation model of maize growth period in Hetao irrigation area based on climatic suitability. China Agricultural Meteorology, 2014 (Volume 35, Issue 1): 62-67.
- [14] You, L. 2013 Inner Mongolia Climate Impact Assessment. Inner Mongolia Climate Center, 2013: 40-41.
- [15] Song, X. F.; Hou, Q. The influence of climatic conditions on potato yield [J]. China Agricultural Meteorology, 2003, (Volume 24, Issue 2): 35-38.
- [16] Li, P. Z. Analysis of Climatic Resources in Potato Cultivation in Chayouzhong Banner [J]. Inner Mongolia Meteorology, 2001, (No. 3): 40-41.
- [17] Gao, T.; Yu, X. Analysis of factors affecting grain yield fluctuation in Inner Mongolia Autonomous Region in recent 50 years [J]. Resources and Environment in Arid Regions, 2003, Vol. 17, (No. 2): 60-64.
- [18] Tang, J. Z.; Wang, J.; Wang, E. L.; Yu, Q.; Yin, H.; He, D.; Pan, X. B. Identifying key meteorological factors to yield variation of potato and the optimal planting date in the agro-pastoral ecotone in North China. Agricultural and Forest Meteorology. 2018; 256–257; 283–291.
- [19] Zhao, J. F.; Zhan, X.; Jiang, Y. Q; Xu, J. W. Variations in climatic suitability and planting regionalization for potato in northern China under climate change. PLoS ONE (2018), 13 (9): e0203538. <https://doi.org/10.1371/journal.pone.0203538>.
- [20] Yang, L. T.; Jiang, X. P.; Dabu, S. L. T.; Qian, J. X.; Zhang, G. L. GIS-based vulnerability assessment of climate change to potato growth. Disaster Science, 2021, 36 (01): 100-105.