

Analysis of Climate Suitability for Potato Critical Growth Periods in Inner Mongolia under Climate Change: Postprint

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Abstract

Inner Mongolia is one of the major potato production regions in China, and investigating the regional adaptability of potatoes in the context of climate change holds important practical significance. Based on daily meteorological observation data from 119 stations in the Inner Mongolia region and employing a climate suitability assessment model, this study analyzes the spatial characteristics and variation trends of climate suitability during the potato flowering to harvest period in Inner Mongolia for two climatic periods: 1961-1990 and 1991-2015. The results show that: 1) The comprehensive climate suitability during the potato flowering to harvest period in Inner Mongolia from 1961-2015 is 0.62, indicating generally favorable climatic conditions, with sunshine suitability > temperature suitability > precipitation suitability. 2) In terms of spatial distribution, temperature suitability exhibits a 'low-high-medium' zonal distribution from west to east; precipitation suitability increases from west to east and from north to south; sunshine suitability is high in the west and low in the east. Synthesizing the effects of the three elements—light, temperature, and water—the eastern sections of the northern and southern foothills of the Yinshan Mountains and the southern foothill region of the Greater Khingan Range constitute high-value areas for climate suitability, possessing climatic resource advantages for potato production. 3) In terms of interdecadal variation, during 1961-1990, the comprehensive climate suitability demonstrated an overall increasing trend, with the exception of slight decreases in the northeastern and northwestern parts; during 1991-2015, the comprehensive suitability in most areas shifted from an increasing to a decreasing trend. 4) In the context of climate change, the climate suitability during the potato flowering to harvest period in Inner Mongolia decreased at a trend rate of 0.0040×10^{-1} from 1961-2015, with sunshine suitability remaining essentially stable, while precipitation suitability and temperature suitability exhibited decreasing trends to varying degrees, which is unfavorable for potato growth and development. Therefore,

management of moisture and heat conditions should be emphasized during the potato flowering to harvest period, and the findings can provide a reference for the utilization and management of climate resources for potatoes.

Full Text

Suitability Analysis of Key Potato Growth Stages in Inner Mongolia Under Climate Change

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Abstract

Inner Mongolia is one of China's major potato-producing regions, making it practically important to explore regional potato adaptation under climate change. Based on daily meteorological observations from 119 stations in Inner Mongolia, this study employs a climate suitability assessment model to analyze spatial characteristics and trends of climate suitability during the potato flowering-to-harvest period across two climatic epochs: 1961-1990 and 1991-2015. The results show: (1) The comprehensive climate suitability index for the potato flowering-to-harvest period in Inner Mongolia from 1961-2015 was 0.62, indicating generally favorable climatic conditions, with sunshine suitability > temperature suitability > precipitation suitability. (2) Spatially, temperature suitability exhibited a "low-high-medium" zonal pattern from west to east; precipitation suitability increased from west to east and from north to south; and sunshine suitability was high in the west and low in the east. Considering the combined effects of light, temperature, and water, the eastern sections of the northern and southern Yinshan slopes and the southern Daxing'anling region represent high-value areas with advantageous climatic resources for potato production. (3) Temporally, during 1961-1990, the comprehensive climate suitability showed an overall increasing trend except for slight declines in the far northeast and far northwest. During 1991-2015, most regions shifted from increasing to decreasing trends. (4) Under climate change from 1961-2015, climate suitability during the potato flowering-to-harvest period in Inner Mongolia declined at a rate of $0.0040 \cdot 10a^{-1}$. Sunshine suitability remained essentially stable, while precipitation and temperature suitability showed varying degrees of decline, which is unfavorable for potato growth and development. Therefore, attention should be paid to water and heat management during the flowering-to-harvest period. These results provide references for the utilization and management of potato climate resources.

Keywords: Climate change; Inner Mongolia; Potato; Flowering-to-harvest period; Climatic suitability; Temperature suitability; Sunshine suitability; Precipitation suitability

1. Introduction

Potato (*Solanum tuberosum* L.) planting area and total production in Inner Mongolia rank among the highest in China. As an advantageous region for potato industry development, vigorously promoting potato production in Inner Mongolia is significant for meeting national needs regarding agricultural transformation, structural adjustment, and potato staple food initiatives. Potatoes prefer cool climates and are not heat-tolerant; their yield and quality are closely related to climatic conditions in planting regions, which affect growth, development, and yield formation differently. Under global climate change, meteorological elements including light, temperature, and precipitation in Inner Mongolia have changed significantly [1], while agricultural production is one of the most sensitive sectors to climate change [2]. Most potato-producing areas in Inner Mongolia are located in ecologically fragile farming-pastoral transition zones where growth and development are vulnerable to meteorological conditions. Research shows that climate change impacts on crops vary greatly by region, with opposite conclusions drawn from different areas [3-4]. Therefore, studying potato climate suitability not only enhances monitoring of potatoes in advantageous production areas but also provides references for national potato climate change impact assessments.

Research on climate change impacts on crops and climate suitability has a long history with increasingly rich results. Dai et al. [5] analyzed spatiotemporal variation characteristics of light-temperature-water suitability for winter wheat (*Triticum aestivum* L.) in Hebei Province from 1981-2010. Ren et al. [6] studied cotton (*Gossypium* spp.) climate suitability in Henan Province, finding a decreasing trend with obvious regional differences. Yao et al. [7] found that temperature and light suitability for maize (*Zea mays* L.) increased while precipitation suitability decreased from 1971-2008. Wang et al. [8] concluded that temperature, precipitation, and climate suitability for winter wheat in Jiangsu Province showed weak increasing trends from 1971-2010, while sunshine suitability showed a weak decreasing trend.

Previous research has focused primarily on crops such as maize, wheat, rice (*Oryza sativa*), and cotton [9-15], with relatively few studies on potato growth climate suitability. The flowering-to-harvest period is crucial for potato tuber expansion and nutrient accumulation, accounting for approximately half of the total growth period and representing the key stage for yield formation. This period typically occurs from July to September, when potatoes are sensitive to meteorological changes. Therefore, this study constructs a climate suitability index for the key potato growth period in Inner Mongolia using ArcGIS technology, analyzing spatiotemporal variation characteristics of potato climate suitability under climate change to provide a scientific basis for rational climate resource utilization and planting structure optimization.

1.1 Study Area Overview

Inner Mongolia Autonomous Region (97°12' -126°04' E, 37°24' -53°23' N) is a high-latitude, high-altitude area with a temperate continental climate. Light resources are abundant, with annual sunshine hours exceeding 2,700 h in most areas and total solar radiation increasing from northeast to southwest. Annual precipitation ranges from 50-450 mm, decreasing from the wetter northeast to the dry west. The annual mean temperature is 0-8°C. Most areas of Inner Mongolia have cool climates with abundant sunshine and large diurnal temperature ranges, creating suitable environmental conditions for potato production. Potatoes are cultivated throughout Inner Mongolia, representing one of the most widely distributed and stable crops in the region in terms of area and production [16].

1.2 Data Processing

Meteorological data for 1961-2015 were obtained from 119 automatic weather stations in Inner Mongolia, including daily observations of average temperature (°C), maximum temperature (°C), minimum temperature (°C), precipitation (mm), relative humidity (%), sunshine hours (h), wind speed ($\text{m}\cdot\text{s}^{-1}$), and atmospheric pressure (hPa). Potato yield and planting area data were sourced from statistical departments. Agricultural zone data came from the Inner Mongolia Department of Agriculture and Animal Husbandry. Potato growth period data were obtained from agricultural meteorological observation reports provided by the Inner Mongolia Meteorological Bureau, with developmental periods at each station determined by proximity to potato observation sites (Figure 1 [Figure 1: see original paper] and Table 1). Meteorological indicators including three-base-point temperatures and crop coefficients for the potato flowering-to-harvest period were derived from relevant literature [17-18]. Origin 9.1 and Microsoft Excel 2013 were used for meteorological data analysis and chart production, while ArcGIS 10.2 was employed to create regional maps and spatiotemporal distribution maps of climate suitability.

1.3 Climate Suitability Models

1.3.1 Potato Temperature Suitability Temperature suitability [19] is calculated using the following formula:

$$F_t = \frac{(t - t_l) \cdot (t_h - t)^B}{(t_0 - t_l) \cdot (t_h - t_0)^B} \cdot \frac{t_h - t_0}{t_0 - t_l}$$

where F_t is temperature suitability; t is daily average temperature; t_l , t_h , and t_0 are the lower limit, upper limit, and optimal temperature for potato flowering-to-harvest period, respectively. Based on relevant literature [17], the lower limit, upper limit, and optimal temperature for potatoes are 2°C, 30°C, and 18°C, respectively.

1.3.2 Potato Sunshine Suitability Following previous research [20], 70% of astronomical day length is used as the critical value in calculating potato sunshine suitability. When actual sunshine hours exceed 0.7 times the astronomical day length (photoperiod), sunshine suitability is considered 1; when below this value, the ratio of actual sunshine hours to 0.7 times the astronomical day length is used.

$$F_s = \begin{cases} \frac{S}{S_0} & (S < S_0) \\ 1 & (S \geq S_0) \end{cases}$$

where F_s is sunshine suitability, S is actual sunshine hours (h), and S_0 is 70% of the astronomical day length (h) for the period relevant to potato development.

1.3.3 Potato Precipitation Suitability [21]

$$F_r = \begin{cases} \frac{R}{W} & (R < W) \\ 1 & (R \geq W) \end{cases}$$

$$\Delta W = R - W$$

$$W = K_c \times ET_0$$

where F_r is precipitation suitability; ΔW is farmland water surplus/deficit; R is precipitation; W is crop water requirement; K_c is the potato crop coefficient. Following previous research [18], the crop coefficient for the potato flowering-to-harvest period is 0.94; ET_0 is potential evapotranspiration for the period, calculated using the Penman formula as referenced in Mao et al. [22].

1.3.4 Potato Climate Suitability To comprehensively reflect the effects of temperature, precipitation, and sunshine on potato key growth period suitability, a dynamic climate suitability model F for the potato flowering-to-harvest period was constructed using geometric mean and comprehensive product methods based on previous research [23]:

$$F = \sqrt[3]{F_t \times F_s \times F_r}$$

where F_t , F_s , and F_r are temperature suitability, sunshine suitability, and precipitation suitability, respectively.

1.3.5 Climate Trend Rate Climate trend rate was used to analyze trends in climate suitability. Let X_i represent a meteorological variable with sample size n , and t represent the time corresponding to X_i . A simple linear regression equation [24] was established between X_i and t :

$$X_i = at + b$$

where a is the regression coefficient and b is the constant term, estimated using the least squares method. Ten times the value of a represents the climate trend rate per 10 years.

2. Results and Analysis

2.1 Spatial Distribution Characteristics of Climate Suitability

2.1.1 Spatial Distribution of Temperature Suitability From 1961-2015, temperature suitability during the potato flowering-to-harvest period in Inner Mongolia exceeded 0.70, indicating relatively high temperature suitability. The primary reason is that temperatures in Inner Mongolia rise significantly in July, with an average temperature of approximately 19°C during the key growth period, close to the optimal temperature of 18°C for potato growth. High-value areas for temperature suitability were mainly distributed along the northern and southern Yinshan slopes, most central areas, most Yanshan hilly regions, and the southern section of the southern Daxing' anling slopes, reaching above 0.90, with Tuyou Banner as the maximum center (0.94). Temperature suitability was slightly lower in most of Alxa League and northern Hulunbuir City, mostly below 0.85.

2.1.2 Spatial Distribution of Precipitation Suitability The precipitation suitability distribution map (Figure 2b [Figure 2: see original paper]) shows that regional precipitation suitability ranged from 0.05-0.55, with large fluctuations and a gradual increasing trend from west to east and from north to south. This pattern primarily reflects the large span of annual precipitation values and significant differences in rainy days across the region: most eastern areas had over 35 rainy days during July-September, while western areas had fewer than 20 days. Precipitation suitability was below 0.2 in the far west, while the southern Yinshan slopes, eastern sections of the northern Yinshan slopes, and most eastern areas were high-value regions, exceeding 0.5 in Qingshuihe and Helingeer of Hohhot City, with other areas being moderate-value zones.

2.1.3 Spatial Distribution of Sunshine Suitability Figure 2c shows that sunshine suitability during the key potato growth period was generally high in Inner Mongolia, as the average sunshine hours during July-September were 789.4 h, indicating abundant sunshine conditions. Sunshine suitability in most areas ranged from 0.88-0.95, with low-value areas mainly distributed in the

southern Daxing' anling region, Arxan area, and the West Liao River irrigation district, at 0.80-0.87.

2.1.4 Spatial Distribution of Comprehensive Suitability The individual factor suitability values indicate that precipitation is the limiting factor for potato growth in central and western regions, while sunshine is an important influencing factor in eastern regions. The combined effects and spatial distribution differences of these three factors determine the spatial pattern of climate suitability during the key potato growth period in Inner Mongolia (Figure 2d). From 1961-2015, agricultural climate (light-temperature-water) resources in Inner Mongolia were generally suitable, with an average comprehensive climate suitability of 0.62, basically meeting potato physiological needs. The far western region had lower values (0.30-0.50). Southern central-western areas and most eastern regions had comprehensive climate suitability above 0.60, possessing advantageous climate resources for potato production. Among these, the southern Daxing' anling slopes, northern and western Yanshan hilly areas, and eastern sections of the northern and southern Yinshan slopes had values of 0.65-0.76, indicating better comprehensive climate conditions. Other areas were moderate-value zones at 0.51-0.60.

2.2 Temporal Variation Characteristics of Climate Suitability

2.2.1 Decadal Variation of Temperature Suitability During 1961-1990, temperature suitability showed weak increasing trends in northern Hulunbuir City, southern Hinggan League, most of Tongliao City, eastern and southern Chifeng City, and areas west of Ulanqab City, while other regions showed weak decreasing trends, with an overall trend rate of $0.0028 \cdot (10a)^{-1}$. During 1991-2015, changes were relatively flat, with temperature suitability showing weak decreases in most areas and a climate trend rate of $-0.0022 \cdot (10a)^{-1}$ (Figure 3 [Figure 3: see original paper]).

2.2.2 Decadal Variation of Precipitation Suitability Potato precipitation suitability showed large variation amplitudes. During the first 30 years, the climate trend rate ranged from -0.0654 to $0.1363 \cdot (10a)^{-1}$, with increasing trends in the northern and southern Daxing' anling slopes, eastern Xilingol League, middle sections of the northern Yinshan slopes, and most of the Hetao Irrigation District, while other areas showed decreasing trends, with an overall average increase rate of $0.0057 \cdot (10a)^{-1}$ (Figure 4a [Figure 4: see original paper]). During 1991-2015, most areas showed decreasing trends (overall decrease rate of $0.0108 \cdot (10a)^{-1}$), with more obvious declines in the Yanshan hilly areas, and only slight increases in the western section of the southern Yinshan slopes, eastern Hetao Irrigation District, and middle sections of the northern Yinshan slopes (Figure 4b).

2.2.3 Decadal Variation of Sunshine Suitability During 1961-1990, sunshine suitability showed an overall increasing trend with a rate of $0.0078 \cdot (10a)^{-1}$,

distributed as increasing in the west and decreasing in the east. Central-western areas and parts of southern eastern regions showed varying degrees of increase, with decreasing amplitude from west to east, while northern eastern areas showed obvious decreasing trends. During 1991–2015, sunshine suitability in the southern West Liao River irrigation district, Ulanqab City, and areas to the west shifted from increasing to decreasing trends, showing weak decreases, with more obvious declines in southern Baotou City, western Hohhot City, and southern Tongliao City. Most eastern areas shifted from decreasing to increasing trends, with the increasing trend area in the northern and southern Daxing’ anling slopes expanding significantly, and an overall climate trend rate of $0.0052 \cdot (10a)^{-1}$ (Figure 5 [Figure 5: see original paper]).

2.2.4 Decadal Variation of Comprehensive Suitability Comprehensive climate suitability showed slight fluctuations between the first and last 30 years. During 1961–1990, except for weak decreases in the northern section of the southern Daxing’ anling slopes, West Liao River irrigation district, western Yanshan hilly areas, northern Alxa, eastern sections of the northern Yinshan slopes, and southwestern sections of the southern Yinshan slopes, most areas showed increasing trends with an average increase rate of $0.0056 \cdot (10a)^{-1}$. During 1991–2015, most areas shifted from increasing to decreasing trends, with an average decrease rate of $0.0057 \cdot (10a)^{-1}$, except for slight increases in most of the northeastern region, Horqin Left Wing Middle Banner in Tongliao City, Baotou City, Ordos City, and eastern Bayannur City (Figure 6 [Figure 6: see original paper]).

2.2.5 Temporal Variation Characteristics of Climate Suitability from 1961–2015 Figure 7 [Figure 7: see original paper] shows that from 1961–2015, temperature suitability and sunshine suitability in Inner Mongolia were relatively high, fluctuating between 0.85–0.93 and 0.84–0.96, respectively, with maximum amplitudes of 0.08 and 0.12. Mean precipitation suitability (0.31) was significantly lower than temperature and sunshine suitability, fluctuating between 0.22–0.41 with an amplitude of 0.19. Analysis of disaster data from the past 30 years in Inner Mongolia shows that extensive drought occurred in 2002, with severe droughts in 2000 and 2007, corresponding to precipitation suitability values of 0.228, 0.225, and 0.216, respectively. Comprehensive climate suitability fluctuated between 0.55–0.69 with an amplitude of 0.14. These results indicate that light and temperature resources are relatively good in Inner Mongolia, while precipitation resources somewhat limit potato growth.

Over the past 55 years, the linear trend rate of temperature suitability during the potato flowering-to-harvest period in Inner Mongolia ranged from -0.0246 to $0.0136 \cdot (10a)^{-1}$, with weak decreasing trends in southern eastern and western regions and weak increasing trends in other areas (Figure 8a [Figure 8: see original paper]). The linear trend rate of precipitation suitability ranged from -0.0530 to $0.0520 \cdot (10a)^{-1}$, with only the eastern section of the southern Yinshan slopes, middle section of the northern Yinshan slopes, eastern Hetao Irrigation District, and most of Alxa showing weak increasing trends, while other areas showed de-

creasing trends (Figure 8b). The linear trend rate of sunshine suitability ranged from -0.0480 to $0.0358 \cdot (10a)^{-1}$, with most areas showing weak increasing trends except for southern eastern and southern Daxing'anling regions showing decreasing trends (Figure 8c). The linear trend rate of climate suitability ranged from -0.0295 to $0.0269 \cdot (10a)^{-1}$, with weak increasing trends only in the eastern section of the southern Yinshan slopes, middle-western sections of the northern Yinshan slopes, Hetao Irrigation District, and Alxa, while other areas showed weak decreasing trends (Figure 8d). Overall, potato climate suitability in Inner Mongolia showed a weak decreasing trend, with sunshine suitability slightly increasing, temperature suitability weakly decreasing, and precipitation suitability declining. Analysis of the two 30-year periods reveals that the variation characteristics of comprehensive suitability are similar to those of precipitation suitability, indicating that precipitation impacts on potato key growth periods in Inner Mongolia will increase over time.

3. Conclusions and Discussion

- 1) Under climate change, the spatial distribution characteristics of climate suitability during the key potato growth period in Inner Mongolia from 1961–2015 were: temperature suitability generally showed a “low-high-medium” zonal pattern from west to east; precipitation suitability increased from west to east and from north to south; sunshine suitability was high in the west and low in the east. The comprehensive climate suitability distribution was jointly influenced by these three factors, with values above 0.60 in the eastern sections of the northern and southern Yinshan slopes and the southern Daxing'anling region, indicating advantageous climate resources for potato production. The far western region had the lowest values, with other areas being moderate-value zones.
- 2) The comprehensive climate suitability index for the key potato growth period in Inner Mongolia was 0.62, indicating that overall climatic conditions are relatively superior and suitable for potato cultivation. Sunshine suitability was higher than temperature suitability, which was higher than precipitation suitability, further demonstrating that light and heat conditions are better than water conditions, with water being the main limiting factor for potato cultivation.
- 3) Temporally, comprehensive climate suitability showed slight fluctuations between the first and last 30 years. During 1961–1990, except for weak decreases in the northern section of the southern Daxing'anling slopes, West Liao River irrigation district, western Yanshan hilly areas, northern Alxa, eastern sections of the northern Yinshan slopes, and southwestern sections of the southern Yinshan slopes, the overall trend was increasing. During 1991–2015, most areas shifted from increasing to decreasing trends, with an average decrease rate of $0.0057 \cdot (10a)^{-1}$, except for slight increases in most of the northeastern region, Horqin Left Wing Middle Banner in Tongliao City, Baotou City, Ordos City, and eastern Bayannur

City. Decadal analysis reveals that variation characteristics of comprehensive suitability are similar to those of precipitation suitability, indicating that precipitation impacts on key potato growth periods in Inner Mongolia will increase over time.

- 4) From 1961-2015, under climate change, different regions and climatic factors showed inconsistent trends in climate suitability during the key potato growth period. Slight increases occurred in the eastern section of the southern Yinshan slopes, middle-western sections of the northern Yinshan slopes, Hetao Irrigation District, and Alxa, while other areas showed decreasing trends. Sunshine suitability showed a weak increasing trend, while precipitation and temperature suitability showed varying degrees of decline. Overall, climate change has had a weak negative effect on climate suitability during the potato flowering-to-harvest period in Inner Mongolia, which is unfavorable for potato growth and development.

Inner Mongolia has a vast territory with complex and diverse landforms and climatic conditions from east to west. This study analyzed spatiotemporal distribution characteristics of potato climate suitability in Inner Mongolia from 1961-2015 based on climate suitability indices. The results show obvious differences in potato climate suitability, with high-value areas (0.61-0.76) in the eastern sections of the northern and southern Yinshan slopes and the southern Daxing' anling region, where industrial advantages are evident due to refined field management [25]. The West Liao River Plain has good irrigation conditions, and the northern Daxing' anling agricultural area has abundant precipitation but slightly insufficient light and temperature, resulting in moderate climate suitability (0.51-0.60). The Hetao Irrigation District and Tumochuan Plain have relatively lower climate suitability (0.31-0.50) compared to other regions. Comparison with national potato advantage production areas shows that current potato cultivation in Inner Mongolia is distributed in medium and high climate suitability value regions, indicating that the evaluation method can reflect the distribution of potato climate suitability during key growth periods and is consistent with actual planting conditions. Temporally, comprehensive climate suitability during the potato flowering-to-harvest period in Inner Mongolia showed a weak decreasing trend from 1961-2015, consistent with findings from Xiong et al. [26-27]. This is because annual precipitation in Inner Mongolia showed an overall increasing trend, annual sunshine hours showed a weak decreasing trend, and annual mean temperature showed an increasing trend, especially pronounced since the mid-to-late 1990s. Cold winter days decreased while hot summer days increased; during 1996-2009, 12 out of 14 years had above-average temperatures. Research indicates that temperature increases have significant negative effects on potato growth [28], leading to increased evaporation and intensified local drought [29-30], which causes precipitation and temperature suitability to decline, affecting the matching of light-temperature-water conditions and reducing comprehensive suitability, thereby inhibiting normal potato growth and development. Therefore, enhanced technical measures against high temperatures and precise field water management

during the potato flowering-to-harvest period are needed.

Under climate change, crop growth and development processes will undergo certain changes [31]. This study evaluated regional potato cultivation suitability using climate suitability indices for temperature, precipitation, sunshine, and their combined effects, and analyzed variation characteristics of suitability during key growth periods across two time periods, which is important for understanding regional potato adaptation in Inner Mongolia and has significant application value. The results provide theoretical support for improving water-heat management during key potato growth periods and rational cultivation, offering strong reference value for objective and effective potato production in Inner Mongolia.

Potato growth is influenced by multiple factors including soil conditions, topography, variety characteristics, and pests and diseases, with different meteorological elements producing different effects during different growth stages. More in-depth and detailed research is needed in future work to further improve the actual representation capability of suitability indices.

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