The Trend of GIS-Based Suitable Planting Areas for Chinese Soybean Under the Future Climate Scenario

Wen-ying He, Le-le Wang, Xiao-li Luo and Guo-jun Sun

Abstract In this study, it gets the distribution of suitable planting areas for soybean by taking the soybean, one of the Chinese major food crops, as the object of study, adopting the multi-criteria evaluation (MCE) method, combining the climate, soil and crop growing conditions, and making use of the geographical information system (GIS) technology. The time zone for future climate chosen in this study is between 2071 and 2100. This chapter gets the distribution of suitable planting areas for soybean in the future presuming that the sunlight, soil, topography, and other factors are the same as those between 1971 and 2000 while the precipitation (PRE) and temperature change. In addition, it has compared it with the suitable planting areas at present. The results show that under the future climate conditions, the most suitable planting areas for spring soybean mainly concentrate in Inner Mongolia near to Jilin as well as the southeast of Gansu and southern Ningxia. Compared with the former suitable planting areas, the overall most suitable planting areas for spring soybean is moving to northwest. Under the future climate conditions, the total suitable planting area for Chinese spring soybean is 5,957,960 km^2, taking 79.35 % of the total area. Under the future climate conditions, the most suitable planting area for summer soybean mainly concentrate in western Jilin, western Liaoning, part of Hebei, Beijing, eastern Shandong, southern Jiangsu, Zhejiang, central of Fujian, part of Anhui, southern Hunan, northern Guangxi, southeast of Guizhou, Chongqing, Hubei, and part of Shanxi. The most suitable planting areas for summer soybean are scattered without obvious regularity and extend to Liaoning, Jilin, and northern Hebei to the north and to Shandong peninsula to the east and to the Yangtze River region to the south. The total suitable planting area of summer soybean is 6,118,013 km^2 taking 81.47 % of the total.

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1 Introduction

The future climate change taking the global warming as the main characteristic has caused serious impact to the global ecological environment as well as economy and society. In particular with the global warming, the national agricultural planting area has changed a lot and the agricultural products production has decreased greatly in Brazil and other countries, which has caused the high concern of international society. China as a country with large population although has the third largest land area, it is in lack of per capita arable land area because of the large population. It is of great importance to the normal development of national economy to effectively evaluate the suitable planting area for a variety of good crops. With complicated climate conditions and fragile ecological environment in China, climate change will mainly cause the occurrence rates of water deficiency of major food crops, frequent natural disasters of agriculture, and fluctuation of food production increased a lot. Under the context of global warming, the occurrence degree of meteorological disasters of China's agriculture, water shortage and agricultural pests and diseases will be intensified while it is of great importance to make research on the effect of climate change to the crop planting in ensuring the national food security and promoting rural economic development [1] as well as the ecological environment protection and sustainable development.

This study makes evaluation to the suitable planting areas of Chinese soybean based on the multi-criteria evaluation (MCE) of GIS. MCE-GIS method, that is on the basis of geographical information, assists the decision-maker to find the most suitable one in the large amount of alternatives by using the eligible criteria and their weights and uses an evaluation matrix to solve a practical problem or target [2] and make the result visualized. This kind of method combining MCE and GIS has got extensive application in the species suitability evaluation and decision analysis.

The current researches on future climate mainly focus on the PRE and temperature change two aspects. The future climate time zone chosen in this research is between 2071 and 2100, presuming that the sunlight, soil, topography, and other factors are the same as those between 1971 and 2000 while the PRE and temperature change. The distribution of suitable planting area for soybean in the future with the current suitable planting areas was compared.

The future PRE and temperature data used in this research are the result of future regional climate change simulation and estimation performed by regional climate mode RegCM3 of International Center of Physical (ICTP, the Abdus Salam International Centre for Theoretical Physics, Italy) used by the researchers of National Climate Center and it is the ground temperature and PRE data within China in the context of SRES A2 greenhouse gas emission between 2071 and 2100 of later twenty-first century. Special report on emissions scenarios (SRES) is to get a future emission situation of greenhouse gases and sulfate aerosols through a series of factor hypothesizes (such as population growth, economic growth, technology development, environmental conditions, and global and fairness principle) and then estimate the climate changes in the global and regional in the future. Because of the differences in social and economic development that will appear in the future, it usually needs to make the corresponding different emission scenarios and SRES is one of them.

2 Research Method

This study establishes the spatial database of regional weather, topography, soil, and other environment conditions by taking the GIS as the main technological methods, choosing the soybean eligible factor, collecting the environmental condition data and making use of the spatial analysis module, spatial interpolation module, re-classification module, weight overlay, and other modules, and then, it uses MCE method to study the spatial distribution area and suitable levels of potential planting area for soybean.

The main steps are as follows:

1. Choose eight factors that affect the growth and development of soybean based on the expert advice and related literature records.
2. Establish the database of impact factors, mainly separate into database of meteorological factors and database of soil types.
3. In ArcGIS 9.2 software, use the spatial analysis module and spatial interpolation module to change the impact factors into raster layers.
4. Based on the expert advice and related literature records, use the re-classification module to make re-classification for the variable raster layer and get the suitable level figure of each factor that affects the soybean growth.
5. The agriculture experts make pairwise comparison for each factor by making use of analytic hierarchy process (AHP) and use MATLAB to calculate the weight of each impact factor.
6. Use the weight overlay module in the ArcGIS 9.2 software to make weight overlay for appropriate level figures of each impact factor and get the suitable planting area figure of Chinese soybean.

2.1 Data Collection and Collation

2.1.1 Eligible Factor Selection of Soybean

Among many impact factors that affect the soybean growth and development, based on the principles of domination, difference, and operability, etc. and referring to the expert [3–14] advice as well as the related literature records, it selects eight factors of representative and influential: accumulated temperature at the whole growth period (≥10 °C), PRE at the whole growth period, sunshine duration at the whole growth period, the maximum temperature at the whole growth period (August), the minimum temperature at the whole growth period (May), PH value of soil, field moisture capacity, and type of soil.

2.1.2 Data Collection of Environmental Conditions for Soybean Growth

The future PRE and temperature data used in this research are the result of future regional climate change simulation and estimation performed by regional climate mode RegCM3 of International Center of Physical (ICTP, the Abdus Salam International Centre for Theoretical Physics, Italy) used by the researchers of National Climate Center, and it is the ground temperature and PRE data within China in the context of SRES A2 greenhouse gas emission between 2071 and 2100 of later twenty-first century. The resolution is 20 km and the range covers the whole China as well as the surrounding East Asia. The temperature is surface temperature (TAS): It is the temperature near the ground (usually at the height of 2 m), unit: K; PRE: including all kinds (rain, snow, large-scale precipitation and convective precipitation, etc.), unit: mm/day; region: longitude 60°E–149°E and latitude 0.5°N–69.5°N.

The meteorological data under the current climate conditions needed in this study is downloaded from the Web site of China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). The data can be mainly divided into three types:

1. Data of Month: including monthly average maximum temperature, monthly average minimum temperature, monthly average temperature, and monthly PRE etc. of the nationwide 794 meteorological stations from 1971 to 2000.
2. Data of Day: the time range of this data is also between 1971 and 2000 and also covers 794 meteorological stations of the whole mainland. The main contents of the data are daily temperature data within the soybean growth period, etc.
3. Data of Sunshine: the data of this part not only include the part of mainland, but also cover the meteorological stations of our surrounding areas, totally more than 2,300. The time range is also from 1971 to 2000 and the main content of data is average sunshine hours.

The topographical data used in this study are from National Administration of Surveying, Mapping, and Geoinformation. The resolution of this data is 1:250,000 and the main contents include the following: contour lines, data of national rivers and lakes, administrative boundary data of national borders and provincial boundaries.

The soil data of this study is from Institute of Soil Science, Chinese Academy of Science, including 0–20 cm soil properties of raster data and the national 1: 1,000,000 soil types data.

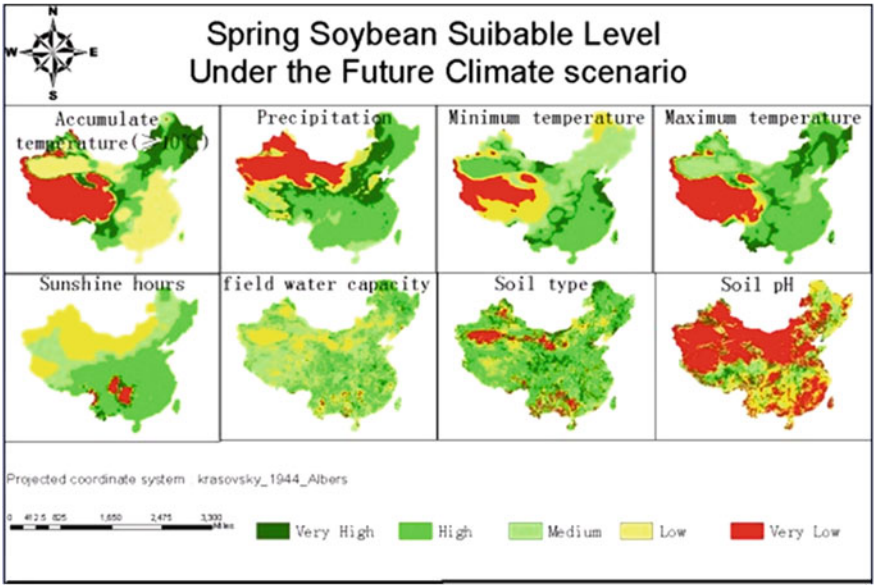


Fig. 1 Factor map for spring soybean under the future climate scenario, including suitability levels for each factors

The land-use data in this study are from Environmental and Ecological Science Data Center for West China and include the land-use map with national 1-km resolution.

2.2 Spatial Database Establishment of National Climate, Topography, and Soil

2.2.1 Establishment of Climate Database

According to the oat crop mapping from Fan Wan [15] and others as well as the interpolation method comparison of each meteorological factor in the potential suitable planting area of wheat from Yaxiong Chen and others [16], this study follows the results of their researches: the maximum temperature and minimum temperature are got from the average monthly data of 1971–2000 and 2071–2100, adopting the ordinary Kriging method to make the interpolation. ≥10 °C accumulate temperature is got from the average daily material of 1971–2000 and 2071–2100, adopting the IDW method to make the interpolation. PRE in the growing period is got from the average daily data of 1971–2000 and 2071–2100, adopting the UK method to make the interpolation and get the figures of appropriate level of each factor (Figs. 1, 2).

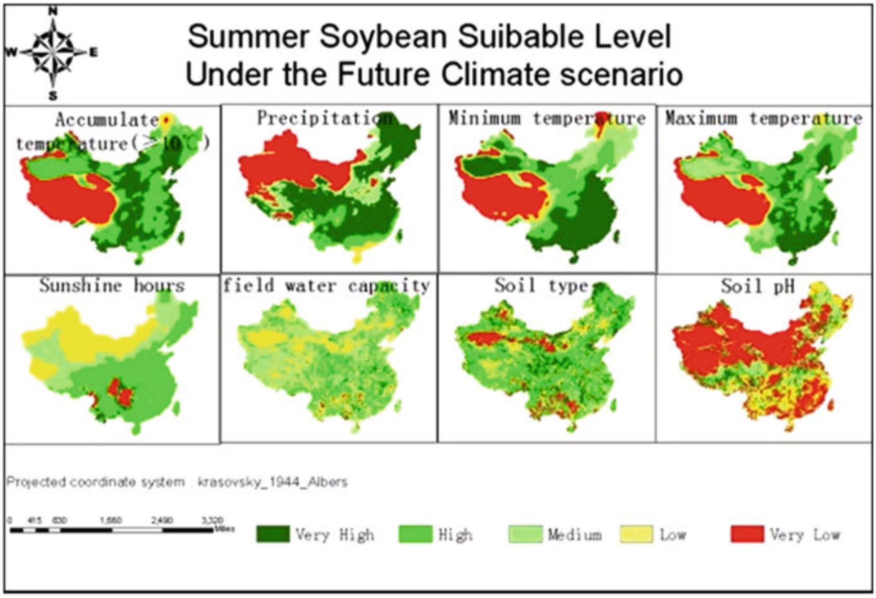


Fig. 2 Factor map for summer soybean under the future climate scenario, including suitability levels for each factors

2.2.2 Establishment of Topography Database

The national 1:250,000 contour lines data are from National Administration of Surveying, Mapping, and Geoinformation. Because the contour lines are only expressing the partly elevation values within the range, therefore in this application, we have made the contour lines into digital elevation model (DEM), which is finished in the ArcGIS 9.2 software. First, in the 3D analysis module of Arcinfo, change the original contour lines data into triangulated irregular network (TIN) and then change it into DEM. Merging the already-got scattered DEM in the spatial analysis module and get the national DEM, from which extract the elevation information. Usually, the DEM is expressed in elevation matrix composed of ground regular network unit, which has been widely applied to the description of topography and has replaced the contour representation in traditional topographical maps [17]. It adopts Albers projection and the size of raster is 1,000 × 1,000 m.

2.2.3 Establishment of Soil Database

The national 1:1 billion soil type data and 0–20 cm soil property raster data are from Institute of Soil Science, Chinese Academy of Science. Firstly, sample the data and get 99.034 point data. Make Kriging spatial interpolation for these point

Table 1 Specific level per factor for the spring soybean

Factor	Level of suitability				
	Very high	High	Medium	Low	Very low
Accumulate temperature (≥10)	3,300–2,400	2,400–2,200 or 3,300–3,800	2,200–1,900 or 3,800–4,000	>4,000	<1,900
Precipitation (mm)	540–370	370–320 or 540–1,000	320–250 or >1,000	320–180	<180
Minimum temperature (°C)	22–20	20–18	18–10	10–4	<4
Maximum temperature (°C)	25–22	22–18	18–16	16–4	<14 or >25
Sunshine hours (h)	750–700	750–1,200	1,200–1,350	1,350-1,700	<700
Field water capacity	0.80–0.80	0.7–0.5	0.5–04	0.4–0.2	<0.2
Soil type	Loam	Sandy/Clay/Silt loam	Sandy/Silt clay	Other class	Sandy
Soil pH	6.0–6.5	6.5–7.0	7.0–7.5	7.5–7.8	<6.0 or >7.8

data in ArcGIS 9.2 to get the soil raster layer and extract the soil texture and soil pH value and other information about each soil type by combining "Chinese Soil Genus Records" and then generate the raster layer of each type of soil in ArcGIS 9.2 adopting Albers projection and the size of raster is 1,000 × 1,000 m. National 0–20-cm soil layer property raster data, including organic matter content, total nitrogen, total phosphorus, total potassium content data, are obtained through projection conversion and re-sampling project kasovsky-1940-Albers equal area projection and the size of raster is 1,000 × 1,000 m.

2.3 Classification of Suitable Area and Suitable Level of Soybean

Based on the established database and refer to the related literature, the weather and soil data were classified into five levels according to suitability, respectively very high, high, medium, low and very low (Tables 1, 2), and through the reclassification in ArcGIS, the proper-level figure of each factor that affects the soybean growth (Figs. 1, 2) was got.

The weight of eligible factor was determined, and the agriculture experts make pairwise comparison for each factor by making use of AHP and use MATLAB to calculate the weight of each impact factor (Table 3).

Table 2 Specific level per factor for the summer soybean

Factor	Level of suitability				
	Very high	High	Medium	Low	Very low
Accumulate temperature (≥10 °C)	3,400–2,800	2,800–2,400 or >3,400	2,400–2,000	2,000–1,000	<1,900
Precipitation (mm)	650–360	650–1,000	360–250	>1,000	<250
Minimum temperature (°C)	30–20	20–15	15–10	10–8	<8
Maximum temperature (°C)	28–25	25–22	22–18	18–16	<16
Sunshine hours (h)	750–700	750–1,200	1,200–1,350	1,350–1,700	<700 or >1,700
Field water capacity	0.80–0.80	0.7–0.5	0.5–04	0.4–0.2	<0.2
Soil type	Loam	Sandy/Clay/ Silt loam	Sandy/Silt clay	Other class	Sandy
Soil pH	6.0–6.5	6.5–7.0	7.0–7.5	7.5–7.8	<6.0 or >7.8

Table 3 Analysis results of the comparison

	AT	PR	MI	MA	SH	WC	ST	PH
AT	1	9/8	3/2	6/5	6/1	7/1	8/1	8/1
PR	8/9	1	4/3	75	7/1	8/1	9/1	9/1
MI	2/3	3/4	1	23	2/1	3/1	4/1	4/1
MA	5/6	5/7	3/2	1	3/1	4/1	5/1	5/1
SH	1/6	1/7	1/2	1/3	1	7/6	9/6	9/6
WC	1/7	1/8	1/3	1/4	67	1	9/7	9/7
ST	1/8	1/9	1/4	1/5	6/7	7/9	1	1
PH	1/8	1/9	1/4	1/5	6/7	7/9	1	1

The corresponding weight coefficient of each factor after calculation includes the following: accumulated temperature 0.2657, PRE 0.2744, minimum temperature 0.1633, maximum temperature 0.1633, sunshine hours 0.0505, field water capacity 0.0410, soil pH 0.0328, and soil type 0.0328. Making use of the got weight coefficiencies as well as the weight overlay module in the ArcGIS 9.2 software, the weight overlay for the proper-level map of each influence factor was made and then the already-got level diagram and land-use map extracting water, sand, desert and alpine wilderness were overlaid, and finally, the potential suitable planting area diagram for Chinese soybean at present and in the future was got (Figs. 3, 4).

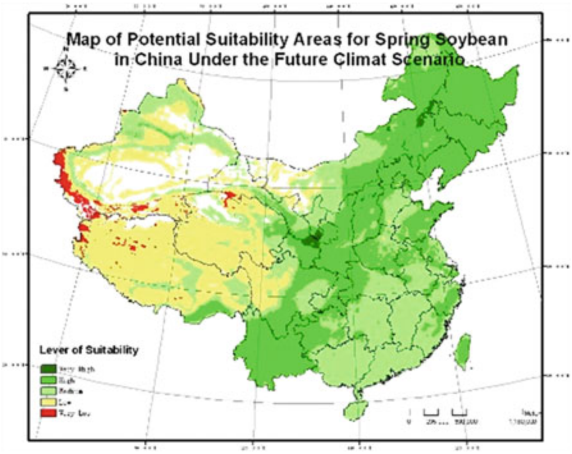


Fig. 3 Map of potential suitability areas for spring soybean in China under the future climate scenario

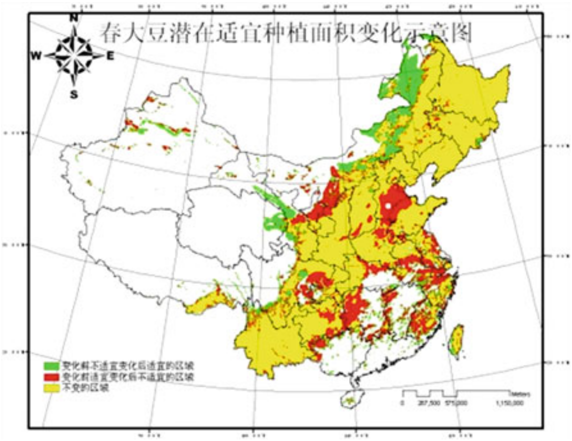


Fig. 4 The sketch map of change in potential suitability areas for the spring soybean

3 Results and Analysis

3.1 The Change in Potential Suitable Planting Area for Chinese Spring Soybean Under Future Climate

If very high, high, and medium suitable planting areas were chosen, the suitable planting area for Chinese spring soybean under the future climate is 5,960,271 km^2, which takes 79.35 % of the total area (Fig. 3).

It can be seen from Fig. 8, the most suitable planting areas for spring soybean under future climate change concentrate in the area of Inner Mongolia near to Jilin as well as southeast of Gansu and southern Ningxia. Relatively suitable planting areas mainly concentrate in Heilongjiang, Liaoning, Jilin, northeast of Mongolia,

Table 4 Change in potential suitability areas for the spring soybean in each province units: km^2

	2071–2100	1971–2000	Difference		2071–2100	1971–2000	Difference
Shandong	247,645	296,011	−48,366	Liaoning	142,448	142,422	26
Anhui	54,319	95,448	−41,129	Jilin	180,240	172,723	7,517
Jiangsu	48,035	107,584	−59,549	Hubei	107,050	217,002	−109,952
Zhejiang	45,544	65,452	−19,908	Heilongjiang	406,537	400,373	6,164
Yunnan	358,723	337,432	21,291	Henan	118,492	159,466	−40,974
Xinjiang	19,377	32,930	−13,553	Hebei	127,201	172,325	−45,124
Xizang	48,011	53,577	−5,566	Guizhou	129,977	162,693	−32,716
Tianjing	6,624	10,868	−4,244	Guangzhou	16,976	55,202	−38,226
Taiwan	25,630	18,732	6,898	Gansu	151,729	120,491	31,238
Shanghai	4,142	4,848	−706	Fujian	26,228	59,974	−33,746
Shannxi	181,211	197,020	−15,809	Beijing	14,368	16,077	−1,709
Qinhai	28,986	1,881	27,105	Chongqing	54,885	61,525	−6,640
Ningxia	12,196	29,166	−16,970	Sichuan	180,315	184,621	−4,306
Neimenggu	607,313	402,242	205,071				

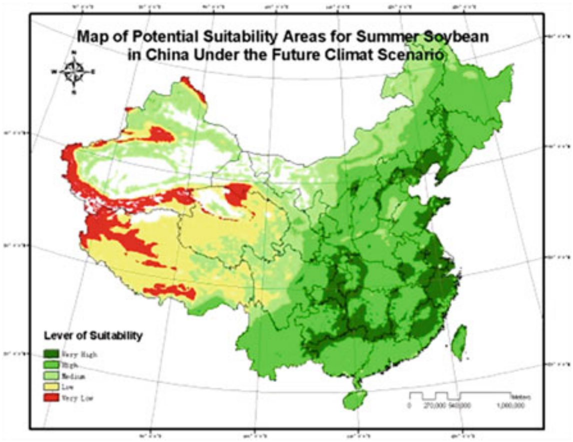
northern Heibei, southwest of Henan, Shandong, northern Anhui, Shanxi, Shanxi, southeast of Gansu, central Sichuan, Yunnan, southeast of Chongqing, western Hubei, western Guizhou, eastern Zhejiang, Taiwan, Anhui, and part of Fujian.

It can be seen from the contract GIS-based Evaluation of spring Soybean Growing Areas Suitability in China [18] and Fig. 8, under the future climate, the overall most suitable planting area for spring soybean will move to northwest. Most of the places of China can grow spring soybean and the most unsuitable areas for spring soybean will decrease obviously. With the global warming, the accumulated temperature will increase, which will make the suitable planting area for spring soybean wider, and in Tibetan, such high-altitude region, the unsuitable planting area is decreasing gradually.

Very high and high, two levels, suitable planting areas were chosen, and the suitable planting area of each province with national provincial boundary map was extracted and also the planting area of spring soybean in each province at present with those under future climate was compared (Table 4, Fig. 4).

It can be seen from Table 4, the potential suitable planting areas of spring soybean under future climate change such as Neimenggu, Qinghai, and Gansu get the highest increase with Inner Mongolia increasing by 205,071 km^2, Qinghai increasing by 27,105 km^2, Gansu increasing by 31,238 km^2, and the northeast place nearly unchanged. There is a decrease in the southern planting area such as Anhui, Jiangsu, Guizhou, and Fujian. The general increasing trend is moving to inland and northern part. Under future climate, the total suitable planting area is 3,344,202 km^2, which has a little decrease when compared with the current suitable planting area of 3,583,131 km^2. But the most unsuitable planting area is 57,730 km^2, which has an obvious decrease when compared with the current suitable planting area of 522,459 km^2 [18]. With the global warming, the suitable planting area of spring soybean within China is becoming wider and wider.

Fig. 5 Map of potential suitability areas for summer soybean in China under the future climate scenario



3.2 *The Changes of Potential Suitable Planting Areas for Summer Soybean in China Under Future Climate Conditions*

If very high, high, and medium suitable planting areas were chosen, the suitable planting area for summer soybean in China under future climate conditions is 6,118,013 km^2, which takes 81.47 % of the total area (Fig. 5).

From Fig. 5, the most suitable planting areas for summer soybean under future climate conditions focus on western Jilin, western Liaoning, parts of Hebei, Beijing, eastern Shandong, southern Jiangsu, Zhejiang, central Fujian, parts of Anhui, southern Hunan, northern Guangxi, southeast of Guizhou, Chongqing, Hubei, and parts of Shannxi.

We can learn from the comparison between Fig. 5 and GIS-based Evaluation of summer Soybean Growing Areas Suitability in China [18] that the change in most suitable planting area for summer soybean is relatively scattered without obvious regularity to the north, extend to Liaojing, Jilin and northern Hebei; to the east, extend to Shandong peninsula and to the south, extend to Yangtze River region. Most of the places around the country can grow summer soybean and the areas not suitable for summer soybean planting is decreasing.

Choose very high and high two levels as the more suitable planting area and extract the suitable planting area of each province with the national provincial boundary map and make comparison of the planting areas for summer soybeans of each province under the future climate conditions and current climate conditions [18] (Table 5, Fig. 6).

From Table 5, under future climate change, the potential suitable planting areas which have great increase include Inner Mongolia, Yunnan, Shanxi, Liaoning, Jilin, Heilongjiang, Guizhou, Gansu, Chongqing and Sichuan. The Inner Mongolia increased by 270,380 km^2, Shanxi by 47,454 km^2, and Heilongjiang by 72,987 km^2. Under the change in future climate, the planting areas of summer

Table 5 Change in potential suitability areas for the summer soybean in each province units: km^2

	2071–2100	1971–2000	Difference		2071–2100	1971–2000	Difference
Shandong	285,209	265,018	20,191	Liaoning	142,452	128,331	14,121
Anhui	134,260	128,782	5,478	Jilin	180,240	134,702	45,538
Jiangsu	247,500	245,671	1,829	Hubei	380,354	357,752	22,602
Zhejiang	96,873	92,274	4,599	Heilongjiang	362,846	289,859	72,987
Yunnan	344,033	82,474	261,559	Henan	152,033	163,191	−11,158
Xinjiang	7,060	19,706	−12,646	Hebei	163,652	144,904	18,748
Xizang	32,758	39,457	−6,699	Guizhou	175,988	135,713	40,275
Tianjing	10,869	10,868	1	Guangzhou	397,023	372,644	24,379
Taiwan	34,325	23,537	10,788	Gansu	95,973	51,830	44,143
Shanghai	4,910	4,910	0	Fujian	117,523	109,451	8,072
Shannxi	191,363	143,909	47,454	Beijing	16,124	15,933	191
Ningxia	7,988	1,622	6,366	Chongqing	81,724	70,433	11,291
Neimenggu	358,066	87,686	270,380	Sichuan	208,760	153,886	54,874

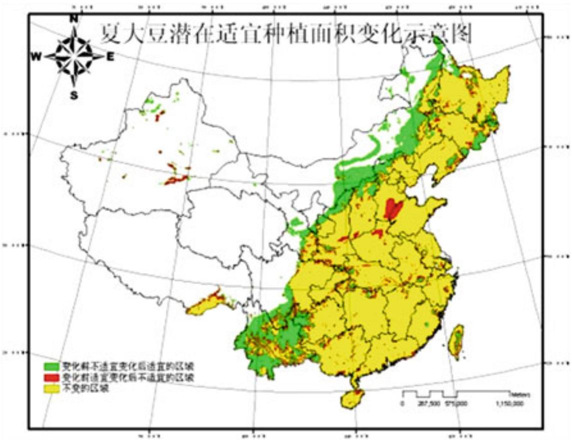


Fig. 6 The sketch map of change in potential suitability areas for the summer soybean

soybean in most of the provinces of China have increased. The areas of northeast and Inner Mongolia have increased in overall and only that of Xinjiang has decreased. The overall increasing trend is moving to inland and northern parts. The total planting area under future climate is 4,259,635 km^2 and has great increase when compared with the current suitable planting area of 3,306,593 km^2. The unsuitable planting area is 350,769 km^2, which has decreased a little when compared with the current suitable plating area of 695,312 km^2. With the global warming, the suitable planting area of summer soybean within China is becoming bigger and bigger.

4 Discussion

Compared with present, the overall most suitable planting areas for spring soybean under future climate conditions move to the northwest and the most unsuitable planting area for spring soybean are obviously decreased. The total suitable planting area under future climate is 3,344,202 km^2 and has deceased a little when compared with the current suitable planting area of 3,583,131 km^2 [18]. But the most unsuitable planting area is 57,730 km^2 and is greatly decreased when compared with the current suitable planting area of 522,459 km^2 [18].

Compared with present, the most suitable planting areas for summer soybean under future climate conditions are scattered without obvious regularity and extend to Liaoning, Jilin, and northern Hebei to the north and to Shandong peninsula to the east and to the Yangtze River region to the south. If the best and better planting areas were chosen, it can be seen that the suitable planting areas in inland and northern are increasing. The total suitable planting area in the future is 4,259,635 km^2, which is greatly increased when compared with the former 3,306,593 km^2. The unsuitable planting area is 350,769 km^2, which is decreased a little when compared with the current suitable planning area.

There are also some problems existed in this study. The data under future climate conditions, because of the limitations of the science itself of atmosphere and climate change as well as of computer technology, all the estimation about the future climate change trend has many kinds of uncertainty and it need further development of science and technology. Besides, this study makes the simulation by only presuming that the PRE and temperature change while other factors do not change. But in reality, there are many factors in the future climate will change because the interaction among various factors and each changing factor is not existed alone. For example, the global warming will make the evaporation of soil moisture increase and the organic matter and nitrogen lose, which will lead to further decrease in the PRE in arid regions, the increasing degree of soil erosion and the seriousness of salinity degree, so as to change the soil texture and pH, etc. Therefore, the conditions used in this study are relatively ideal conditions, so the result can only be used as a reference.

In general, global warming will cause the decrease in production potentiality of our major food crops and the increase in the instability. If the effective measures does not take actively against the climate change, the agricultural situation of China will be very challenging based on our existing production levels and security conditions. Therefore, it should take the climate change as the priority strategy to response to the climate change and take the promoting agricultural production and ensuring food safety as our main task to response to the climate change. This study is just from this aim and hoping the study results will have certain reference value for the macrodecision-making of the government.

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References

1. Zhao, J., Yang, X., Liu, Z., Cheng, D., Wang, W., Cheng, F.: The possible effect of global climate changes on cropping systems boundary in China II. The characteristics of climatic variables and the possible effect on northern limits of cropping systems in south China. Sci. Agric. Sin. **43**(9), 1860–1867 (2010)

2. Rico, A.I.: Application of multicriteria evaluation to a spatial conflict in the urban fringe. ITC Msc thesis (2001)
3. Carver, S.J.: Integrating multi-criteria evaluation with geographical information systems. Int. J. Geogr. Inf. Syst. **5**, 321–339 (1991)
4. Wei, L.: Analysis of meteorological factors on soybean growth and yield. Heilongjiang Agric. Sci. **2**, 41–43 (2008)
5. Li, X.: The preliminary study of the relationship between climatic conditions and growing development of spring soybean. Crop Res. **4**, 15–17 (1998)
6. Yu, X., Guo, Y.: The effect of meteorological factors on the soybean output. Heilongjiang Meteorol. **2**, 3–4 (2002)
7. Zhou, J., Wang, C., Xu, W.: Comparison between transgenic soybean and non-transgenic soybean in resistance to stresses. J. Ecol. Rural Environ. **22**(2), 26–30 (2006)
8. Wang, Y., Feng, J., Yin, X., Xu, W.: Relationship of soil mechanical composition, pH value and main nutrients with soybean yield in planting areas of Jilin province. Jilin Agric. Univ. **26**(6), 653–658 (2004). Agric. Sci. Bull. **11**(4), 58–59 (2005)
9. Yan, P., Jiang, L., Wang, P., Nan, R., Wang, C., Wang, C.: Analysis of the illumination effect on the soy output from May to July. Heilongjiang Meteorol. **4**, 22–23 (2005)
10. Xiaoming, L.: Study the rate of soybean absorbing the phosphorus in different soil types. Soybean Sci. **2**, 75–77 (2002)
11. Han, X., Qiao, Y., Zhang, Q., Wang, S., Song, C.: Effects of various soil moisture on the yield of soybean. Soybean Sci. **11**, 269–272 (2003)
12. Qiu, J.: Affect of high temperature on soybean production. Soybean Bull. **1**, 12 (2003)
13. Fu, H., Liu, D., Guo, F., Wang, C., Zhao, L.: Effects of different soils on growth, development, yield and quality of small-seed soybean. Jilin Agric. Univ. **24**(5), 21–25, 38 (2002)
14. Chen, Y., Chen, R., Su, Y., Zhong, Z., Zhong, Q., Ji, Y.: Analysis of the meteorological factors affecting summer soybean growth in Huaibei area. J. Anhui Agric. Sci. **32**(4), 745–748 (2004)
15. Wan, F., Wang, Z., Li, F., Cao, H., Sun, G.: GIS-based crop support system for common oat and naked oat in China. Adv. Inf. Commun. Technol. **1**, 209–221 (2009)
16. Chen, Y., Wan, F., Zhou, W., Jia, C., He, W., Guo, R., Sun, G.: Crop mapping in China: the potential distribution of winter wheat. J. Lanzhou Univ. (Nat. Sci.) **45**(FO6), 12–18 (2009)
17. Li, Z., Zhu, Q.: Digital Elevation Model. Wuhan University Press, vol. 10 (2003)
18. He, W., Yang, S., Guo, R., Chen, Y., Zhou, W., Jia, C., Sun, G.: GIS-based evaluation of soybean growing areas suitability in China. Comput. Comput. Technol. Agric. IV–4th, 372–381 (2010)