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Impact of Farmland Change on Soybean Production Potential in Recent 40 Years: a Case Study in Western Jilin, China

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Abstract: In recent 40 years, the quantity and spatial patterns of farmland in Western Jilin have changed dramatically, which had great impact on soybean production potential. This study used one of the most advanced crop production potential models, the Global Agro-cological Zones model, to calculate the soybean production potential in Western Jilin based on meteorological, terrain, soil and land use data, and analyzed impact of farmland change on soybean production potential during 1975-2013. The main conclusions were the following. First, the total soybean production potential in Western Jilin in 2013 was 89.22 thousand tons. The production potential of eastern area was higher than the other areas of Western Jilin. Second, farmland change led to a growth of 33.03 thousand tons in soybean production potential between 1975 and 2000, and a decrease of 10.30 thousand tons between 2000 and 2013. Third, taking account of two situations of farmland change, the conversion between dryland and other categories, and the change of irrigation percentage led to the total soybean production potential in Western Jilin increased by 23.13 and only 2.87 thousand tons respectively between 1975 and 2000, and increased by 1.13 and 2.81 thousand tons respectively between 2000 and 2013. In general, the increase of soybean potential production was mainly due to grassland and woodland reclamation. The results of this study would be a good reference for protecting safe baseline of farmland, managing land resources, and ensuring continuity and stability of soybean supply and food security.

Keywords: farmland change; soybean; production potential; GAEZ; Western Jilin

1 Introduction

Food is a specialized commodity and an important strategic reserve relating directly to a country's well-being [1,2]. Food security is an important part of national security. Soybean is one

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of the most important food and oil crops in China. Soybean imports in China increased nearly 100 times, from 580 thousand tons in 1996 to 58.38 million tons in 2012, while soybean production has been around 15 million tons and even has started to decline in recent years [3]. Recently, China's agricultural administration has called for a restructuring of agricultural production to increase soybean planting area. Therefore, to improve soybean yield and ensure soybean supply and guide import and export, it is of great significance to study soybean production potential.

At present, research on crop production potential has been extensive and more deepening. Many scholars tried to use more accurate methods to study crop production potential as close as possible to the actual situation. In 1950, Ren discussed land carrying capacity based on agricultural productivity, as the beginning of the study on China's food production potential [4]. In 1978, Dutch scientist Wit *et al.* developed EL-CROS, the first crop computational simulation model [5]. Meanwhile, the influence of climate factors such as temperature and precipitation began to be taken seriously. Some scholars used related functions to modify crop photosynthetic potential, and transited gradually to the study phase of climate production potential [6-8]. Since the 20th century, many food production models have been established and introduced to China., such as the CERES Wheat model [9], EPIC model [10], and WOFOST model [11]. However, the application of the Agro-Ecological Zones (AEZ) model was the most extensive. The AEZ model was developed by the International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO), and it calculated the food production potential under the influence of light, temperation water, soil and terrain [12-15]. Cai *et al.* (2006, 2007) analyzed China's farming, and calculated wheat and rape yield potential using the AEZ model respectively [16,17]. Yu *et al.* (2012) calculated maize production potential in Gansu Province using the AEZ model and predicted that maize production potential would reach to 6072.67 kg/hm^2 in 2015 [18]. Zhan *et al.* (2013) improved the AEZ model and studied dynamics change of the grain productivity in China [19]. Wang *et al.* (2018) studied the spatial-temporal characteristics of winter wheat yield gaps in Henan [20]. Although the research methods of crop production potential are various, one of the most mature models is the Globel Agro-Ecological Zones (GAEZ) model developed from the AEZ model. The GAEZ comprehensively considers the radiation, temperature and other climatic factors that affect the crop growth, such as the length of the growing season, the water needs in different growth stages, *etc.*, according to the characteristics of the crop [13]. The highlight of this study was using the most advanced GAEZ model to calculated soybean production potential of Western Jilin in recent 40 years.

Western Jilin, located on the edge of a farming-pastoral zone in Northern China, is one of three saline-alkali landscapes in the world with soil that severely restricts its use for farming, and soybean is one of the common crops in Western Jilin. Thus, its farmland change would directly have a significant impact on soybean production potential [2]. Therefore, the objective of this study is to use the Global Agro-ecological Zones (GAEZ) model to estimate the soybean

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production potential based on farmland data from 1975, 2000 and 2013, soil data, Digital Elevation model (DEM) data, and meteorological data from the past 40 years, and analyze the impact of farmland change on soybean production potential in Western Jilin. Under the background of the global food security crisis, the results of the research wound provide a basis for the sustainable utilization of land resources and soybean production increase, provide a reference for the optimized allocation of land resources and ensure food security.

2 Materials and methods

2.1. Study area

Western Jilin Province is located in the southwest of Songnen Plain, and located at 43°22′N—46°18′N, 121°36′—126°12′E. It includes 12 counties (or cities), which are Zhenlai, Baicheng, Taonan, Tongyu, Da'an, Qian'an, Songyuan, Fuyu, Qianguo, Songyuan, Changling and Shuangliao. It's the transitional region from black soil in temperate sub-humid areas to chestnut soil in a temperate sub-arid steppe and typical farming-pastoral ecotone. The terrain of Western Jilin is sloped from east and west to the middle [2,21]. The total area is about 5.53 million ha (Figure 1). The annual precipitation is between 370 and 410 mm, and≧10°Cannual accumulated temperature is 2900—3200°C. and Western Jilin now is mainly occupied by farmland, the area of which is approximately 57.46% of the total area.

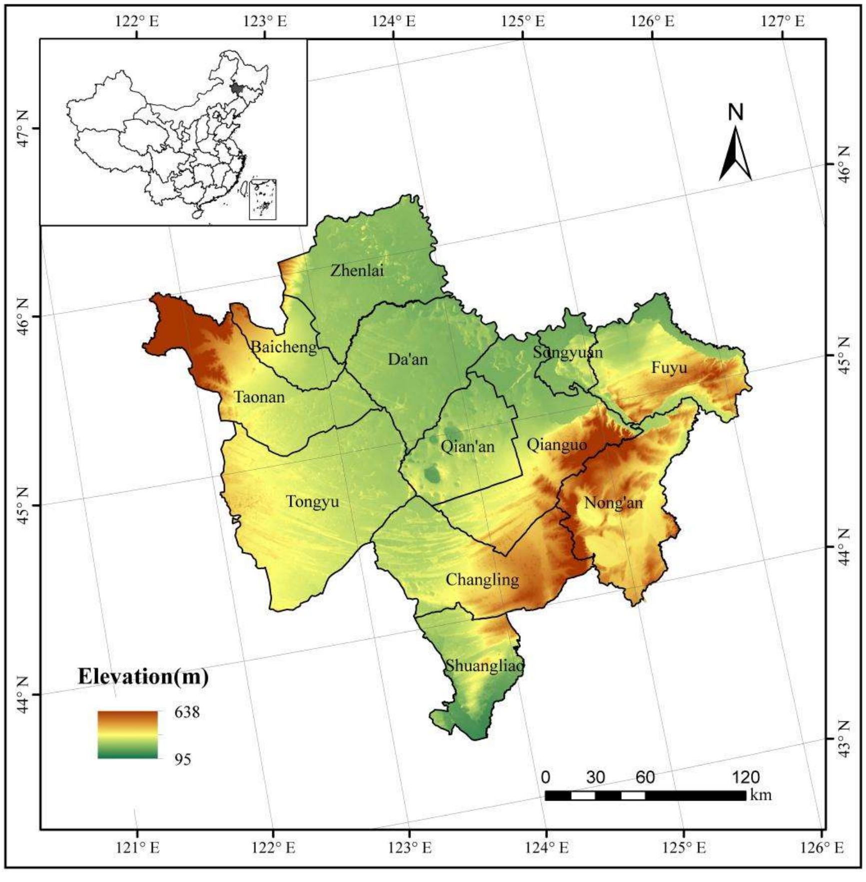

Figure 1. Location of Western Jilin, China

2.2. Data source

Crop production potential within an area was strongly associated with various factors, such as farmland, soil, terrain, and climate, so the input data for this study included land use data, terrain elevation data, soil data, meteorological data and some statistical data.

The land use data of Western Jilin used in this study was extracted from the land-use database developed by the Chinese Academy of Sciences (with a mapping scale of 1:100,000), which included 1975, 2000 and 2013. The land use database was obtained from manual visual interpretation to Landsat TM/ETM images. The land use data was classified into 6 major categories and 25 sub-categories. The six major categories included farmland, woodland, grassland, water bodies, built-up land, and unused land. Due to the severe salinization of farmland and grassland, and the large-scale disappearance of wetland in Western Jilin, alkali-land and marsh were separated from unused land in this study. Meanwhile, dryland and paddy field were separated from farmland. Through field verification, the interpretation precision was >94.3%, which could satisfy the accuracy requirement of 1:100,000 mapping.

The terrain elevation data, high-resolution raster DEM, were derived from the shuttle radar topography mission (SRTM) C-band data [22]. The DEM data with 90m spatial resolution was also processed into slope and aspect data.

The soil data came from the Institute of Soil Science, Chinese Academy of Sciences, which provided the 1:100,0000 scale Soil Map of China, including various soil attributes such as soil texture, organic carbon content, soil acidity, soil drainage ability and so on.

Meteorological data for 1975-2013, which included monthly mean minimum temperature, mean maximum temperature, cumulative precipitation, cumulative radiation, mean relative humidity, mean wind speed at 10m height and wet day frequency. The data were obtained from 19 national meteorological stations maintained by the Chinese Meteorological Administration. The monthly data for the above seven key plant growth factors were interpolated to 1 km resolution by using ANUSPLIN software based on the digital terrain model of Western Jilin [23-25].

Statistical data (such as actual soybean yields and irrigated percentage of each county) derived from Jilin Statistical Yearbook.

2.3. Methodology

2.3.1. Crop production potential simulation method

In this study, crop production potential was simulated using the Global Agro-Ecological Zoning (GAEZ) model. Over the past 30 years, the International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO) have been continuously developing the Agro-Ecological Zone (AEZ) methodology for assessing agricultural resources and potential [26]. Then, the GAEZ model has been developed. The GAEZ model estimated the climatic suitability of crops based on meteorological conditions and then calculated crop production potential step by step taking into account other factors, including light potential

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production (only limiting light), light and temperature potential production (limiting light and temperature), climatic potential production (limiting light, temperature, and water), land potential production (limiting light, temperature, water, soil and terrain), and agricultural potential production (considering limiting agricultural input level and management measures) [27-36].

The detailed calculation procedures of GAEZ model includes six main steps of data processing, namely:

(1) Module1: Climatic data analysis and compilation of general agro-climatic indicators

In Module 1, seven climatic data of a specific year are input to the GAEZ model, and then the module calculates and stores climate-related variables and indicators for each grid-cell.

(2) Module2: Grain-specific agro-climatic assessment and potential water-limited yield calculation.

Module2 calculates the yield of all crop types with the specific climate conditions, considering the limit of water supply.

(3) Module3: Yield-reduction due to agro-climatic constraints

This step is carried out to make explicit the effect of limitations due to soil workability, pest and diseases, and then revises the calculation results of Module 2.

(4) Module4: Edaphic assessment and yield reduction due to soil and terrain limitations

This module evaluates yield reduction due to limitations imposed by soil and terrain conditions.

(5) Module5: Integration of results from Module 1-4 into crop-specific grid-cell databases

This module reads the results of the agro-climatic evaluation for yield calculated in Module 2/3 for different soil classes and it uses the edaphic rating produced for each soil/slope combination in Module 4.

(6) Module 6: Actual yield and production

This module estimates actual yield and production of specific crop types according to the percentage of farmland area to each grid-cell area and shares of rain-fed and irrigated farmland within each grid-cell, using a downscaling method.

Meanwhile, based on the potential cropping system calculated by the GAEZ model, crop production potential is determined considering various cropping systems (including double cropping per year, triple cropping for two years and triple cropping per year). However, Western Jilin has a long and cold winter, so the only cropping system in Western Jilin is single cropping per year.

In this study, soybean was planted in dryland, which included rain-fed land and irrigated land, so the GAEZ model included both irrigated and rain-fed scenarios. Calculations of the potential production for the rain-fed scenarios were based on light, temperature, and water conditions, whereas those for the irrigation scenarios only used light and temperature conditions, assuming sufficient water for crop growth and no water stress. The final crop potential was calculated according to the following formula within each grid-cell.

$$production_t = production_i * i + production_r * (1-i),$$

where $production_t$ represents the total production potential within each grid-cell (kg/ha), $production_i$ represents the production potential under the scenarios in which all the farmland is irrigated land (kg/ha), $production_r$ is the production potential under rain-fed scenarios (kg/ha), and i indicates the percentage of irrigated land area to total farmland area [37].

The flow chart of soybean production potential calculation using the GAEZ model in this study was shown in Figure 2.

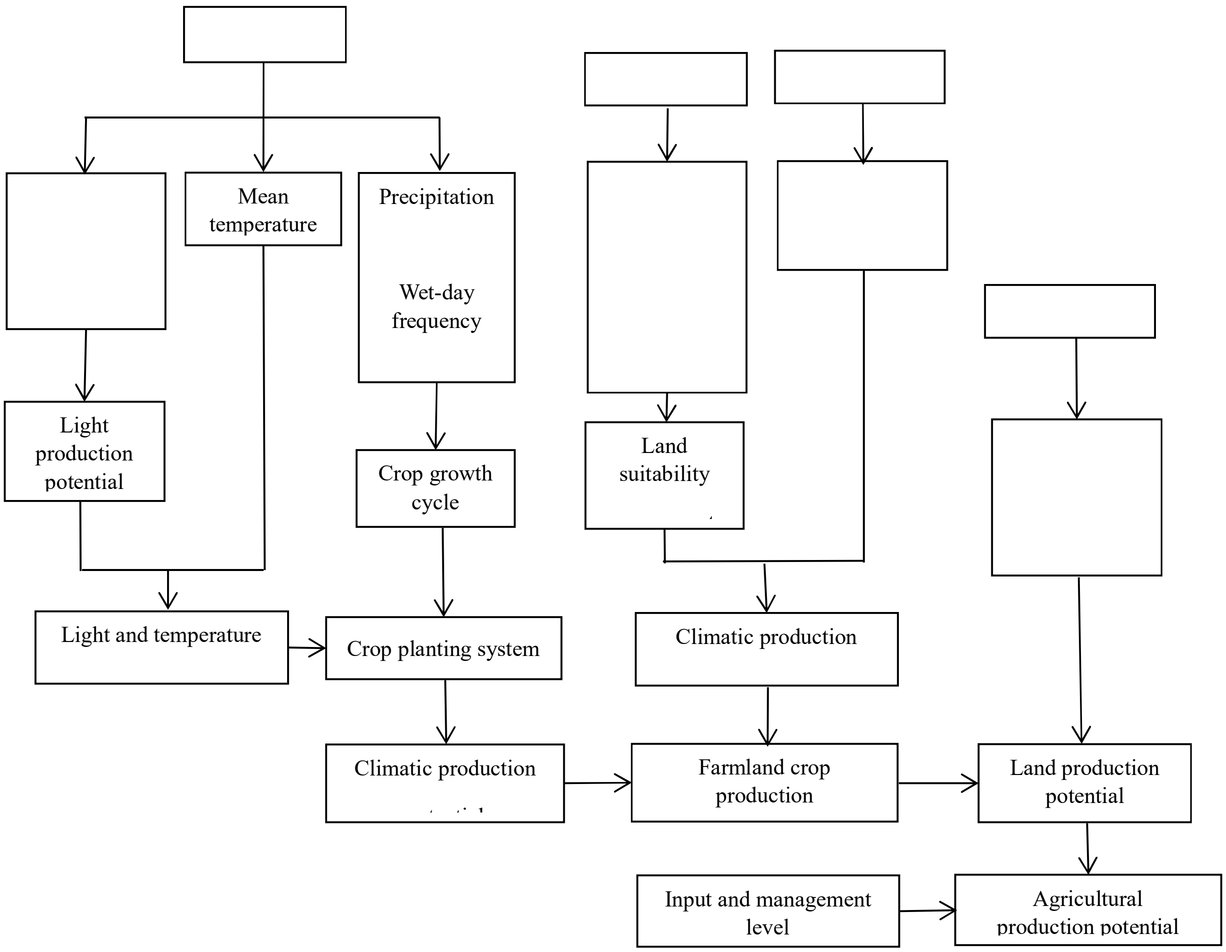

Figure 2. The flow chart of soybean production potential calculation using the GAEZ model

2.3.2. Farmland change impact analysis on soybean production potential

Soybean production potential was deeply affected by farmland change. Farmland change included the conversion between dryland and other categories, and the change of irrigation percentage in dryland. The conversion between dryland and other categories included dryland expansion such as reclamation of grassland and forest, and dryland loss such as urban expansion and farmland salinization. We first analyzed the change of area and spatial distribution characteristics of dryland in Western Jilin between 1975-2000 and 2000-2013, and then considered the impact of farmland change on soybean production potential on the whole. Next, we assumed that, when the conversion between dryland and other categories or the irrigation percentage remained the same, how did the other aspect affect the soybean production potential.

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3. Results and analysis

3.1. Results validation

To verify the accuracy of the simulation results of crop potential production in Western Jilin, we compared the production potential of major crops (including rice, maize and soybean, which account for more than 90% of total grain yields) of 12 counties in Western Jilin in 1975, 2000 and 2013 calculated by using the GAEZ model with actual statistical grain yields from Jilin Statistical Yearbook, setting up regression relation between potential production and actual statistical yields. The total crop potential production of the three years was 28.02 million tons, nearly 1.46 times the actual yields. The correlation between the calculated potential production and actual yields of each county was shown in Figure 3. The cross-correlation coefficient was 0.91, indicating a good correlation. Consequently, the trend in calculated potential production reflected the trend in actual yields. This result could be used to explain the accuracy of the simulation results using the GAEZ model.

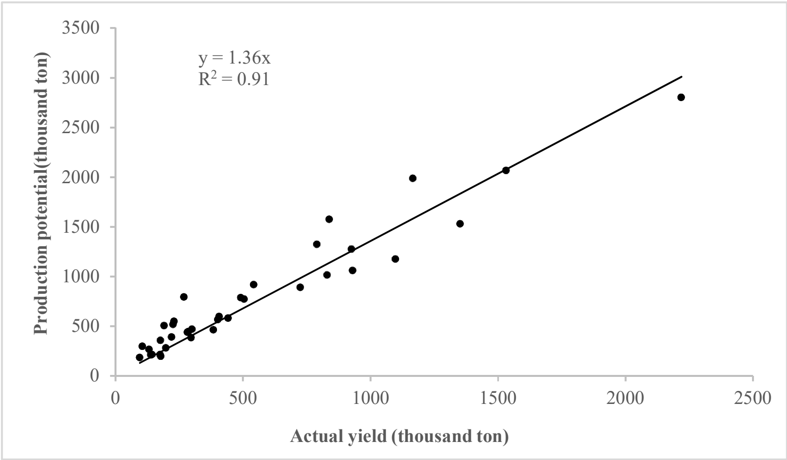

Figure 3. Comparison between production potential and actual yields in each county in 1975, 2000 and 2013

3.2. Spatial contribution characteristics of soybean production potential in Western Jilin in 2013

Although various factors could affect soybean production potential, in order to analyze impact of farmland change of Western Jilin from 1975 to 2013, we assumed that soil and terrain factors were unchanged nearly 40 years, and used monthly mean meteorological data from 1975 to 2013 to analyze the change of soybean production potential led by farmland change.

In 2013, the total soybean production potential of Western Jilin was 89.22 thousand ton, and the average soybean production potential was 1612 kg/ha. It can be seen from the spatial distribution of soybean production potential of Western Jilin in 2013 that the production potential of eastern area was higher than the other areas of Western Jilin (Figure 4). It was mainly because that the farmland density of east was highest and the terrain, soil and climate conditions were suitable for the growth of soybean. It may also because that in the west and south of Western Jilin, land salinization and desertification were serious, and the soil quality was poor, which was not conducive to the growth of soybean. Nong’an had the maximum total production potential of 14.38 thousand tons and average production potential of 2701.68 kg/ha, where the soil was fertile and had suitable hydrothermal

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conditions and there were few land salinization and desertification. In contrast, the area that had the minimum total production potential was Songyuan at 2.43 thousand tons. It was mainly due to the small area of farmland. Tongyu had the minimum average production potential of 938.33 kg/ha, where there were low rainfall, low farmland density, and a large area of sand and alkali-land. The county with the maximum production potential was Shuangliao at 4639 kg/ha (Figure 5).

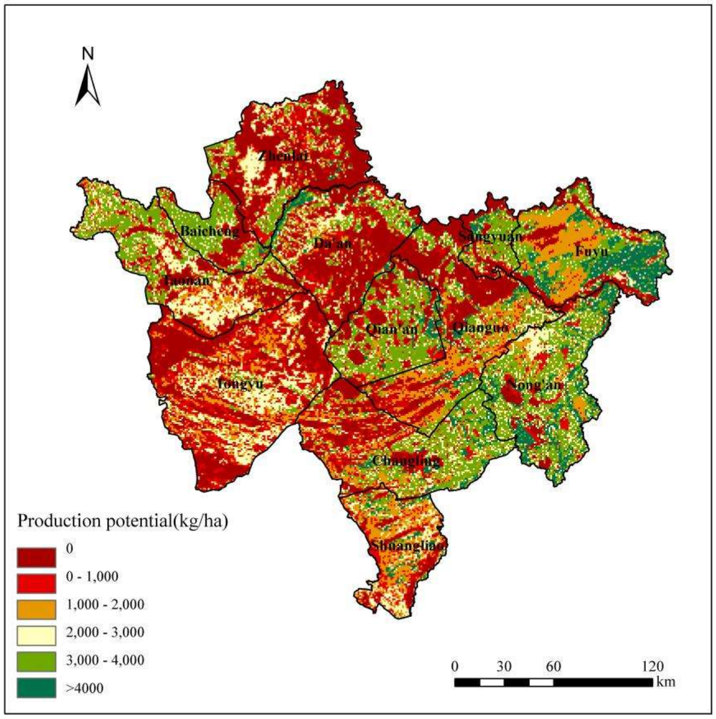

Figure 4. Spatial distribution of soybean production potential in 2013

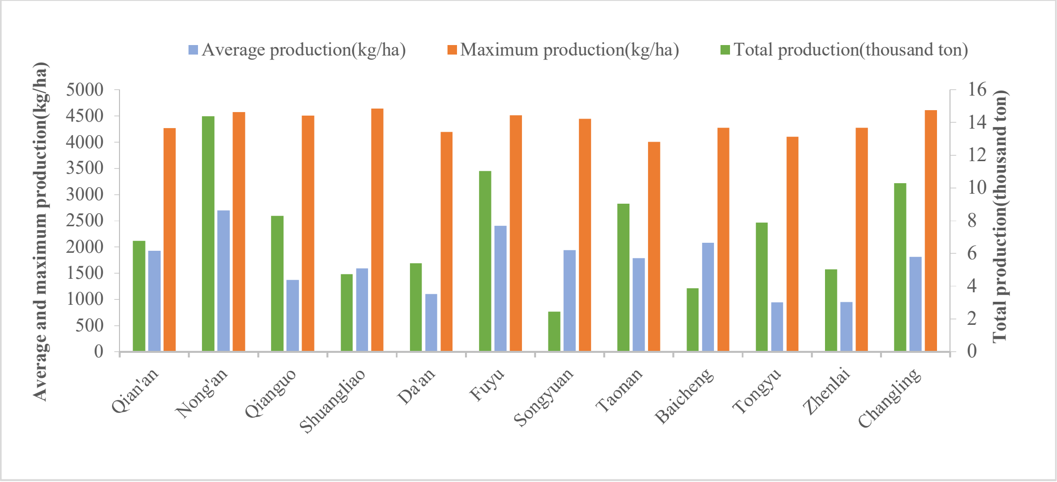

Figure 5. Soybean production potential in Western Jilin in 2013

3.3. Impact of farmland change on soybean production potential

3.3.1. Characteristics of farmland change in Western Jilin between 1975-2013

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From 1975 to 2013, the total area of dryland in Western Jilin showed an increased trend from 1975 to 2000, and was nearly unchanged from 2000 to 2013 (Figure 6). During the first period, the area of dryland increased by 1360.91km^2, with an increase in the center and west of Western Jilin and a decrease in the north. The areas with an increasing dryland were mainly located in the east of Qian'an, the west of Zhenlai, and some areas of Taonan and Tongyu. The areas with a decreasing dryland were sporadically located in the whole area of Western Jilin. The increased dryland mainly came from grassland (1218.45km^2), woodland (717.72km^2), paddy field (159.58km^2) and marsh (154.37km^2). The decreasing dryland mainly converted into woodland (352.16 km^2), built-up land (303.94 km^2), and paddy field (104.67 km^2). During this period, land reclamation was relatively serious, especially grassland and woodland converted to farmland, which accounted for 84.71% of the total increasing dryland. Meanwhile, built-up land expansion also led to part of the dryland reduction.

The area of dryland increased by 224.70 km^2 during the second period. There were 972.37 km^2 of non-dryland converted into dryland and 747.67 km^2 dryland converted into non-dryland. The areas with a decreasing and increasing dryland were all sporadically located in the whole area of Western Jilin. The increasing dryland mainly came from grassland (261.35km^2), paddy field (157.49 km^2), woodland (127.09 km^2) and built-up land (124.35 km^2). The decreasing dryland mainly converted into paddy field (310.46 km^2), built-up land (168.75 km^2) and woodland (126.26 km^2). In this period, as Western Jilin began to pay attention to ecological protection and widespread implementation of returning farmland to woodland and grassland, the area of dryland didn't increase much.

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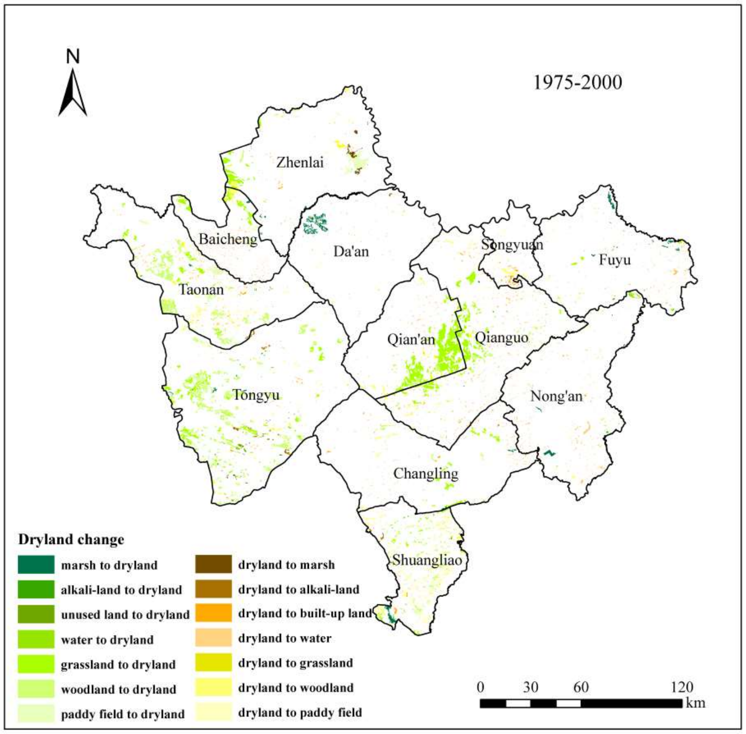

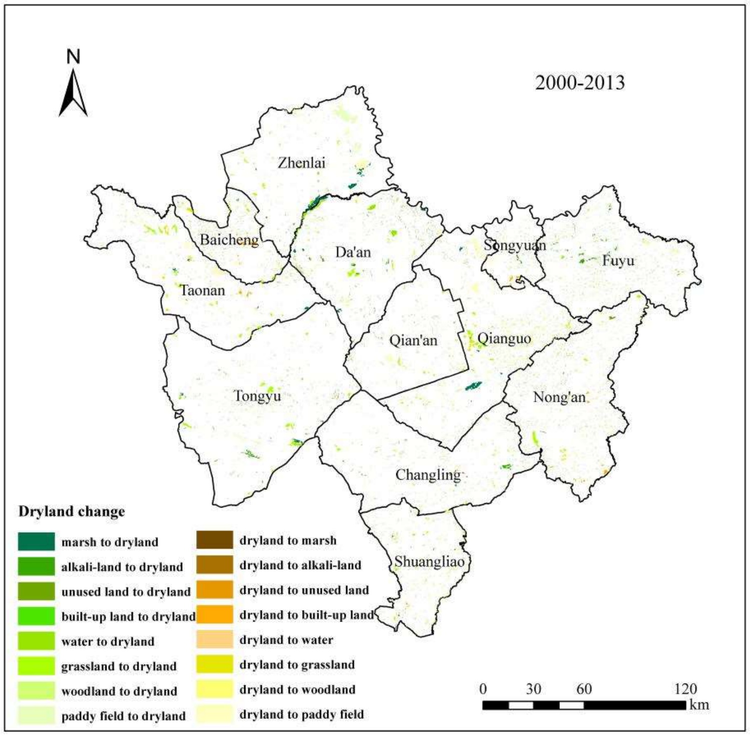

Figure 6. Farmland change between 1975 and 2000, and between 2000 and 2013

3.3.2.Impact of farmland change on soybean production potential from 1975 to 2013

In recent 40 years, the characteristics of soybean production potential change led by farmland change were as follows. The total soybean production potential increased, which was almost located

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in the total area of Western Jilin, especially in Baicheng (between 1000 and 2000 kg/ha) and the southeast of Qian'an (more than 3000 kg/ha). The soybean production potential increased by 36.27 thousand tons, and decreased by 11.77 thousand tons. The net increase was 24.50 thousand tons. In general, the decrease of the soybean production potential decreased were mainly due to urban expansion and returning dryland to woodland and grassland, and the increase were mainly due to reclamation of woodland and grassland.

The net increase of soybean production potential led by farmland change was 33.03 thousand tons during the first period. The soybean production potential increased by 44.71 thousand tons, and decreased by 11.68 thousand tons. The total increase in soybean production potential was about 3.8 times the total decrease. In the most areas of Western Jilin, the average soybean production potential increased by less than 2000 kg/ha, such as Tongyu, Fuyu, Changling and Taonan, and the average soybean production potential increased by more than 3000kg/ha in Baicheng. However in Nong'an and the most areas of Shuangliao, the average soybean production potential decreased by less than 1000 kg/ha (Figure 6). It can been seen from Table 1 that from 1975 to 2000, the increase of soybean production potential was mainly due to reclamation of woodland and grassland, which occupied 96.09 % of the total increase, and returning marsh to dryland was another important reason, especially in Shuangliao and Fuyu. And the increase was mainly distributed in the center of Western Jilin, such as Qian'an, Qianguo and Changling. The decrease was mainly due to urban expansion and returning dryland to woodland and grassland, accounting for 31.59 %, 30.14 % and 22.00 % respectively of the total decrease. The soybean production potential in Qian'an increased by 17.1 thousand tons, decreased by 0.48 thousand tons, and the net increase was 16.62 thousand tons. The net increase in Qian'an was the first in Western Jilin, mainly due to the reclamation of woodland and grassland. The net increase of soybean production potential in Changling was 6.30 thousand tons, which was the second. In Zhenlai, the soybean production potential during the 25 years was nearly unchanged. In Songyuan, Taonan, and Fuyu, the soybean production potential decreased by 0.76, 0.42 and 0.21 thousand tons respectively.

During the second period, the net decrease of soybean production potential led by farmland change was 10.30 thousand tons. The soybean production potential increased by 6.77 thousand tons, and decreased by 17.07 thousand tons. In the western and most central areas of Western Jilin, the average soybean production potential decreased by less than 1000 kg/ha, such as Zhenlai, Tongyu, Qianguo and Songyuan, and even the average soybean production potential decreased by more than 1000kg/ha in Baicheng and Taonan. However in Qian'an and the west of Fuyu, Nong'an, Shuangliao, and the east of Changling, the average soybean production potential increased by less than 1000 kg/ha (Figure 7). In Table 2, from 2000 to 2013, the decrease of soybean production potential was mainly due to urban expansion and returning dryland to woodland and grassland, which accounted for 85.59 % of the total decrease, and it was also due to returning dryland to alkali-land, such as in Taonan and Tongyu. The increased production potential was still mainly distributed in the center of Western Jilin, such as Qian'an, and Qianguo, which were 0.99 thousand

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tons and 0.97 thousand tons respectively. The decreased production was distributed in all of the counties in Western Jilin, especially in Tongyu, Nong'an and Taonan, accounting for 12.01 %, 10.92 % and 10.49 % respectively of the total decrease. The net decrease of soybean production potential in Songyuan was 1.56 thousand tons, which was maximum. It was mainly due to the decrease of dryland caused by returning woodland and grassland. Qianguo was the only county where the soybean production potential increased during the second period (0.14 thousand tons).

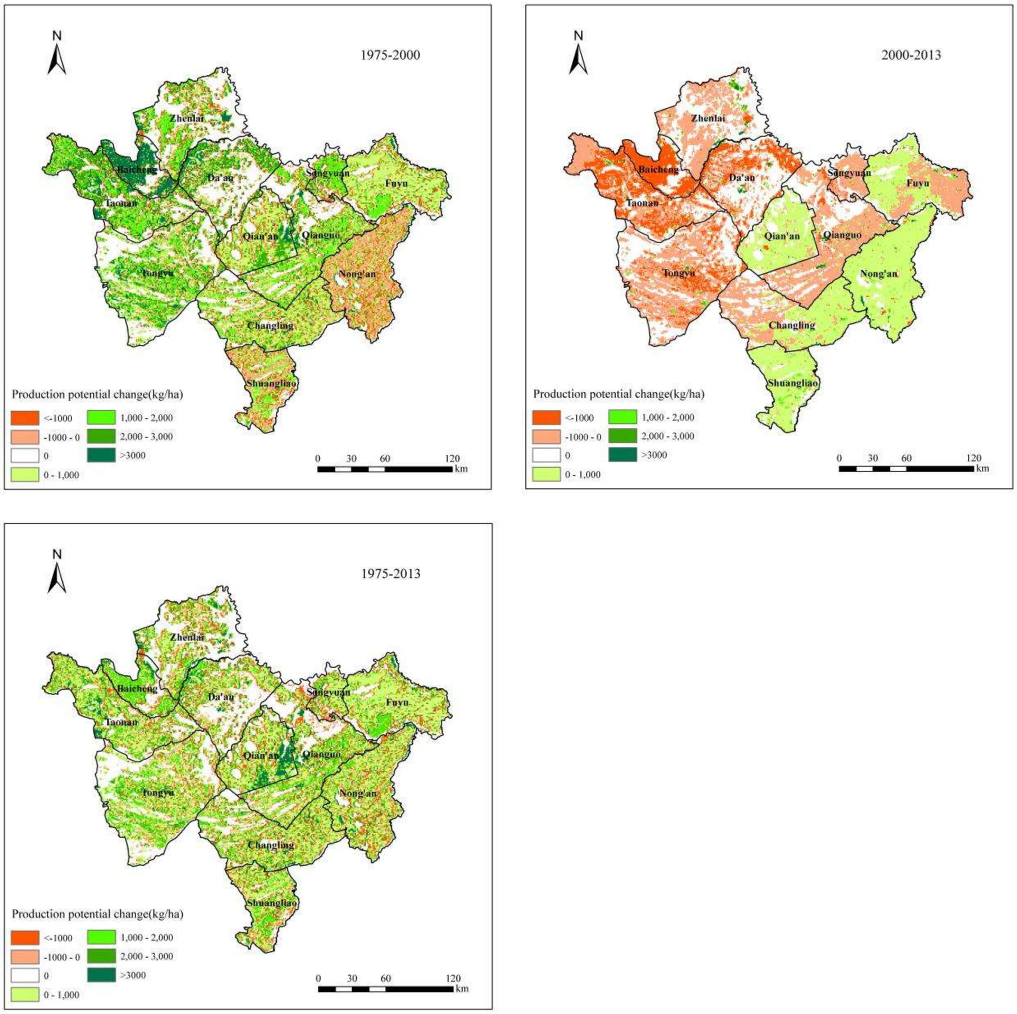

Figure 7. Soybean production potential change between 1975and 2000, between 2000 and 2013, and between 1975 and 2013

Table 1. Impact of farmland change on soybean production potential in Western Jilin during 1975-2000 (thousand ton)

	Qian'an	Nong'an	Qianguo	Shuangliao	Da'an	Fuyu	Songyuan	Taonan	Baicheng	Tongyu	Zhenlai	Changlin g	Total

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	Returing dryland to paddy field	-0.11	0.00	0.00	-0.27	-0.11	-0.31	-0.21	0.00	0.00	0.00	0.00	0.00	-1.01
	Returing forests	0.00	0.00	-0.22	-0.21	-0.45	-0.21	-0.33	-0.71	-0.46	-0.37	-0.34	-0.22	-3.52
	Returing grassland	-0.26	0.00	-0.25	-0.33	0.00	0.00	0.00	-0.13	-0.47	-0.71	-0.42	0.00	-2.57
	Returing water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01
decrease	Urban expansion	-0.11	-0.69	-0.29	-0.34	-0.28	-0.13	-0.22	-0.40	-0.36	-0.45	0.00	-0.42	-3.69
	Returning dryland to alkali-land	0.00	-0.26	-0.02	0.00	0.00	0.00	0.00	-0.22	0.00	-0.12	0.00	0.00	-0.62
	Returning dryland to marsh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.13	-0.13	0.00	-0.26
	Total decrease	-0.48	-0.95	-0.78	-1.15	-0.84	-0.65	-0.76	-1.47	-1.29	-1.78	-0.89	-0.64	-11.68
	Returing paddy field to dryland	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.09	0.09	0.00	0.25	0.00	0.47
	Woodland reclamatio n	7.97	1.79	0.58	0.14	0.57	0.06	0.00	0.78	0.49	0.52	0.11	0.16	13.17
increase	Grassland reclamatio n	9.13	0.59	4.46	0.98	1.23	0.12	0.00	0.13	2.41	3.37	0.60	6.77	29.79
	Returing water to dryland	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03
	Unusedlan d reclamatio	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01

	n													
	Returing alkali-land to dryland	0.00	0.00	0.02	0.08	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.14
	Returing marsh to dryland	0.00	0.16	0.18	0.25	0.13	0.23	0.00	0.05	0.01	0.07	0.01	0.01	1.10
	Total increase	17.10	2.57	5.27	1.45	1.93	0.44	0.00	1.05	3.00	3.99	0.97	6.94	44.71
Net change		16.62	1.62	4.49	0.30	1.09	-0.21	-0.76	-0.42	1.71	2.21	0.08	6.30	33.03

Table 2. Impact of farmland change on soybean production potential in Western Jilin during 2000-2013 (thousand ton)

		Qian'an	Nong'an	Qianguo	Shuangliao	Da'an	Fuyu	Songyuan	Taonan	Baicheng	Tongyu	Zhenlai	Changling	Total
	Returing dryland to paddy field	0.00	-0.13	-0.11	-0.24	-0.21	0.00	-0.43	0.00	0.00	-0.21	0.00	0.00	-1.33
	Returing forests	-0.31	-0.32	0.00	-0.36	-0.54	-0.47	-0.35	-0.69	-0.56	-0.43	-0.39	-0.47	-4.89
	Returing grassland	-0.56	-0.41	-0.31	-0.34	-0.12	-0.21	-0.31	-0.39	-0.27	-0.74	-0.45	-0.43	-4.54
decrease	Returing water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
	Urban expansion	-0.32	-0.74	-0.41	-0.45	-0.31	-0.55	-0.47	-0.42	-0.45	-0.36	-0.41	-0.29	-5.18
	Returning dryland to alkali-land	-0.01	-0.23	0.00	0.00	-0.02	0.00	0.00	-0.29	0.00	-0.28	0.00	0.00	-0.83
	Returning dryland to marsh	0.00	0.00	0.00	0.00	0.00	-0.11	0.00	0.00	0.00	-0.03	-0.16	0.00	-0.30

	Total decrease	-1.20	-1.83	-0.83	-1.39	-1.20	-1.34	-1.56	-1.79	-1.28	-2.05	-1.41	-1.19	-17.07
increase	Returing paddy field to dryland	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.04	0.00	0.17	0.00	0.28
	Woodland reclamation	0.48	0.24	0.13	0.15	0.24	0.00	0.00	0.51	0.24	0.25	0.07	0/31	2.31
	Grassland reclamation	0.51	0.21	0.74	0.51	0.32	0.00	0.00	0.02	0.27	0.32	0.45	0.32	3.67
	Returing water to dryland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Unusedland reclamation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
	Returing alkali-land to dryland	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.06
	Returing marsh to dryland	0.00	0.00	0.08	0.15	0.03	0.13	0.00	0.02	0.00	0.02	0.00	0.01	0.44
	Total increase	0.99	0.45	0.97	0.83	0.59	0.15	0.00	0.60	0.56	0.61	0.69	0.33	6.77
Net change		-0.21	-1.38	0.14	-0.56	-0.61	-1.19	-1.56	-1.19	-0.72	-1.44	-0.72	-0.86	-10.30

4.Discussions

4.1.Impact of two situations of farmland change on soybean production potential

There are two situations that could caused farmland change, namely the conversion between dryland and other categories, and the change of irrigation percentage in dryland. In order to discuss impact of two situations of farmland change on soybean production potential respectively, two scenarios were severally considered to calculated the soybean production potential of 2000 and 2013 once more. In scenario I: the irrigation percentage in 2000 and 2013 was unchanged and the same as 1975, and only the land use categories changed between 1975 and 2013. In scenario II: between 1975 and 2013, only the irrigation percentage changed, and the land use categories in 2000 and 2013 was unchanged and the same as 1975.

4.1.1.Impact of the conversion between dryland and other categories

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Under Scenario I, the total soybean production potential in 1975, 2000 and 2013 were 63.19, 86.32, and 87.45 thousand tons respectively. It indicated that the conversion between dryland and other categories led to the total soybean production potential in Western Jilin increased by 23.13 thousand tons between 1975 and 2000, and 1.13 thousand tons between 2000 and 2013 (Figure 8). During 1975-2000, due to the sharp increase of dryland area, especially grassland and woodland reclamation, the average soybean production potential of the most areas in Western Jilin increased by less than 1000 kg/ha. But in the east of Qian'an, it increased by more than 2000 kg/ha due to grassland reclamation. In a few areas, the average soybean production potential decreased. During 2000-2013, it can be seen that in the west and center of Western Jilin, the average soybean production potential almost decreased by less than 1000 kg/ha, while in the east of Western Jilin, it almost increased by less than 1000 kg/ha. This conformed to the conversion characteristics of dryland between 2000 and 2013.

In western Jilin, the soybean production potential in Nong'an was the maximum during 1975-2013, which were 12.36, 13.5 and 14.27 thousand tons respectively (Figure 9). The production potential in Songyuan was the minimum during this period, and it increased from 1975 (1.95 thousand tons) to 2013 (2.38 thousand tons). The production potential in Tongyu in 2000 was twice as many as in 1975. Qian'an, Taonan, Baicheng and Tongyu were the four counties where the production potential decreased from 2000 to 2013.

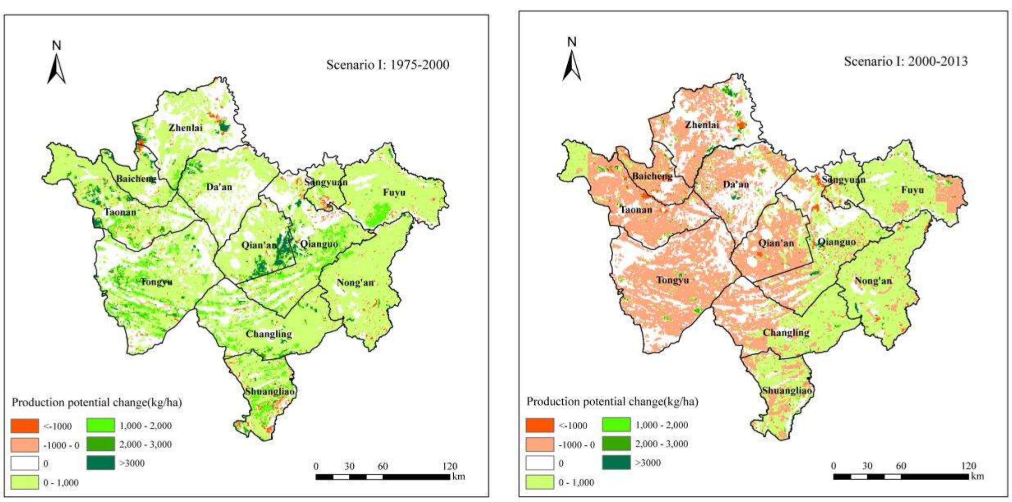
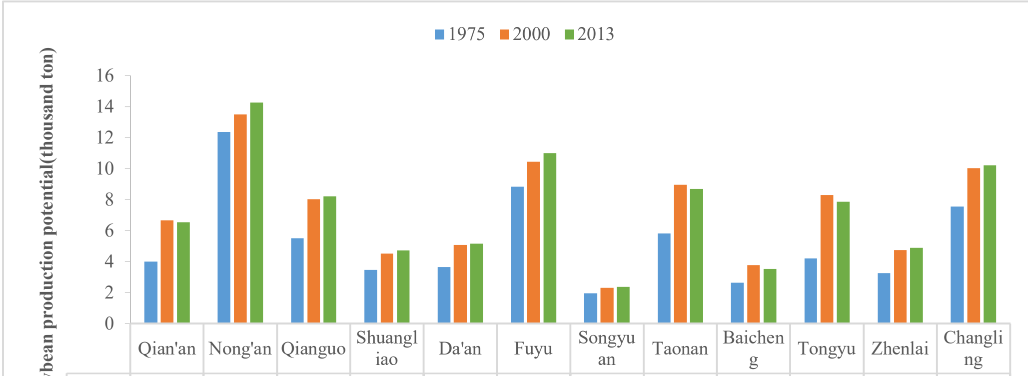


Figure 8. Spatial distribution of soybean production potential change between 1975 and 2000, and between 2000 and 2013 under Scenario I



	Qian'an	Nong'an	Qianguo	Shuangliao	Da'an	Fuyu	Songyuan	Taonan	Baicheng	Tongyu	Zhenlai	Changling
1975	3.99	12.36	5.51	3.47	3.63	8.83	1.95	5.81	2.63	4.2	3.25	7.56
2000	6.67	13.5	8.03	4.52	5.08	10.43	2.29	8.97	3.77	8.3	4.74	10.02
2013	6.54	14.27	8.21	4.72	5.16	10.99	2.38	8.69	3.52	7.86	4.89	10.22

Figure 9. Soybean production potential in Western Jilin in 1975, 2000 and 2013 under Scenario I

4.1.2.Impact of the change of irrigation percentage

Under Scenario II, the total soybean production potential in 1975, 2000 and 2013 were 63.19, 66.06, and 68.87 thousand tons respectively, and the change range of average production potential was between -1000 and 1000 thousand tons (Figure 10). The change of irrigation percentage led to the total soybean production potential in Western Jilin increased by only 2.87 thousand tons between 1975 and 2000, and 2.81 thousand tons between 2000 and 2013. During 1975-2000, the average soybean production potential of the most areas in Western Jilin increased by less than 1000 kg/ha. But in Qian'an, Nong'an and Shuangliao, it decreased by less than 1000 kg/ha because of the decline in the irrigation percentage. During 2000-2013, it can be seen that in Tongyu, the average soybean production potential decreased by less than 1000 kg/ha, while in the other counties of Western Jilin, it increased by less than 1000 kg/ha.

In western Jilin, the soybean production potential of each county was almost unchanged during 1975-2013 (Figure 11). The soybean production potential in Nong'an was still the maximum during 1975-2013, which were 12.36, 12.21 and 12.22 thousand tons respectively. The production potential in Songyuan was the minimum during this period, and it increased from 1975 (1.95 thousand tons) to 2013 (2.42 thousand tons).

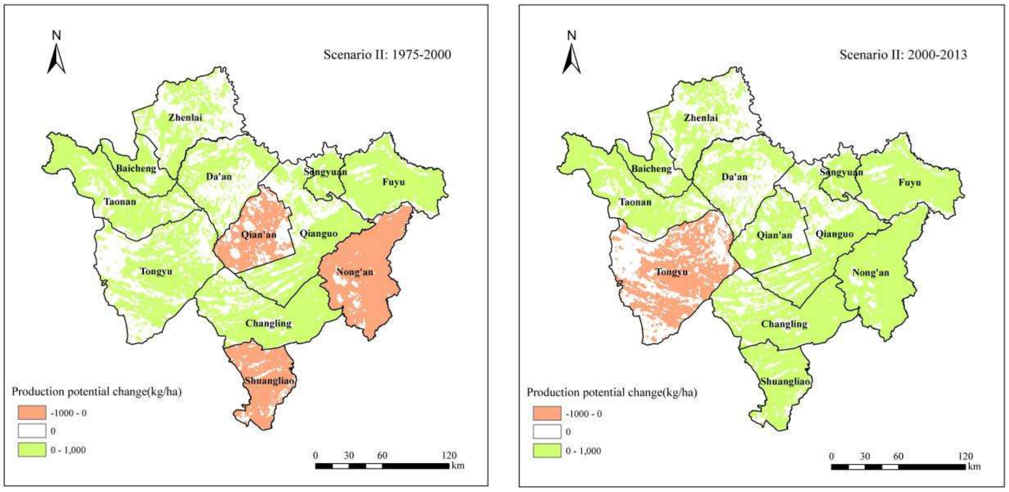
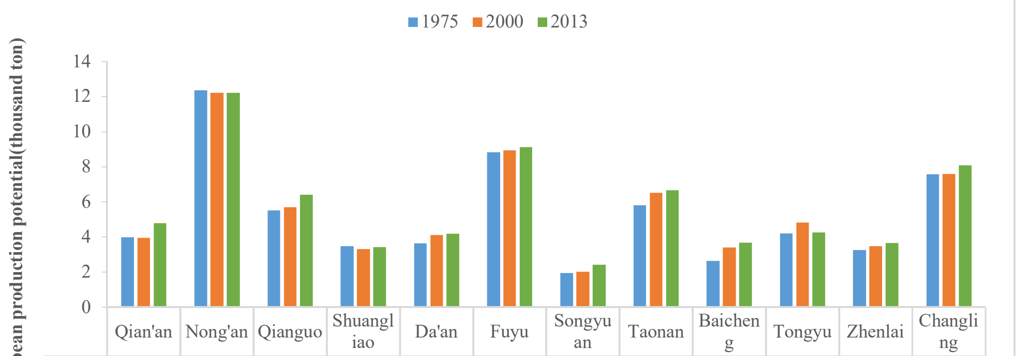


Figure 10. Spatial distribution of soybean production potential change between 1975 and 2000, and between 2000 and 2013 under Scenario II



	Qian'an	Nong'an	Qianguo	Shuangliao	Da'an	Fuyu	Songyuan	Taonan	Baicheng	Tongyu	Zhenlai	Changling
1975	3.99	12.36	5.51	3.47	3.63	8.83	1.95	5.81	2.63	4.2	3.25	7.56
2000	3.95	12.21	5.7	3.31	4.11	8.93	2.03	6.53	3.41	4.83	3.48	7.58
2013	4.79	12.22	6.41	3.42	4.17	9.12	2.42	6.66	3.68	4.27	3.64	8.07

Figure 11. Soybean production potential in Western Jilin in 1975, 2000 and 2013 under Scenario II

4.2.Limitations of the GAEZ model

In this study, we found that the GAEZ model had some limitations. First, monthly mean climatic data were integrated into the GAEZ model, but extreme climate conditions such as extreme temperature and precipitation, may have had large effects on soybean potential production. The impact of these events was not considered in this study. Second, although it was assumed that the water supply was sufficient for crop growth under irrigation scenario in the GAEZ model, the actual availability of water provided by irrigation may be still limited for crop growth in actual practice [1]. Third, levels of input and management are also crucial factors for production potential, such as the use of optimum applications of nutrients and chemical pest, disease and weed control, as well as mechanized production. Due to the difficulty of quantitative research to input and management, it was assumed to be an optimal condition in this study. Therefore, how can this model be better improved so that it can be more accurate to calculate crop production potential, still need to be studied.

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5.Conclusions

This study intended to make a contribution to analyze impact of farmland change on soybean production potential in Western Jilin in recent 40 years. We first analyzed the change of dryland quality and spatial distribution during 1975-2013 in Western Jilin, and then used the GAEZ model to study its impact on soybean production potential.

From 1975 to 2000, the total area of dryland in Western Jilin increased by 1360.91km^2, and increased by 224.70 km^2 from 2000 to 2013. Farmland change led to a net increase of 33.03 thousand tons in soybean production potential between 1975 and 2000, and a net decrease of 10.30 thousand tons between 2000 and 2013. During the first period, the increase of soybean production potential was mainly due to reclamation of woodland and grassland, which occupied 96.09% of the total increase. During the second period, the decrease of soybean production potential was mainly because of urban expansion and returning dryland to woodland and grassland, which accounted for 85.59 % of the total decrease.

We also considered two situations that caused farmland change respectively, namely the conversion between dryland and other categories, and the change of irrigation percentage. The conversion between dryland and other categories led to the total soybean production potential in Western Jilin increased by 23.13 thousand tons between 1975 and 2000, and 1.13 thousand tons between 2000 and 2013. The irrigation percentage was also an important aspect that could affect the production potential, which led to the total soybean production potential in Western Jilin increased by only 2.87 thousand tons during the first period, and 2.81 thousand tons between 2000 and 2013.

Overall, the area of farmland in Western Jilin increased rapidly before 2000. After 2000, Western Jilin paid more attention to ecological environment preservation, and some farmland was changed to non-agricultural utilization mode, resulting in the slow growth of farmland area. Therefore, optimizing the structure and distribution of land use, improving quality of farmland, and correctly analyzing soybean production potential and its regional differences and impact of farmland change on soybean production potential, are good measures to raising the conversion rate of soybean potential production to actual yield. It's also of great significance to protect safe baseline of farmland, manage land resources, and ensure continuity and stability of soybean supply and food security.

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Author Contributions

Luoman Pu, Fei Li and Ranghu Wang designed the research; Luoman Pu and Shuwen Zhang collected and analyzed the data; Luoman Pu wrote the manuscript under the guidance of Shuwen Zhang, Jiuchun Yang and Liping Chang. All authors have read and approved the final manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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