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Assessing sustainable future of import-independent domestic soybean production in China: policy implications and projections for 2030

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Soybean production, integral to sustainable agriculture and reliant on imports, faces vulnerability to international risk factors impacting domestic food security. The 2021 Central Rural Work Conference advocated strategic adjustments for sustainable soybean production amidst resource constraints, trade conflicts, and the lingering impact of COVID-19. This study scrutinizes the developmental framework of China's soybean industry within current domestic policies. This paper uses the soybean sown area and soybean production in each province of China from 1995 to 2020 to measure China's soybean concentration, production layout, and comparative advantage of regional scale, to analyze in depth the overall situation of China's soybean production as well as the differences between regions, and to pave the way for the subsequent soybean production forecast. Further, taking the domestic soybean supply and demand situation in China in 2020 as the base period, while considering the growth values of soybean production under different scenarios, the potential forecasting model is utilized to estimate China's soybean production under different scenarios. The results show that, in terms of inter-annual variability, revealing an upward trajectory from 1995 to 2020, with a shift to major soybean producing areas, notably in the northeast and the Huanghe-Huaihe-Haihe area. From inter-provincial changes, Soybean production on the left and right sides of the "Hu-Huanyong line" has significant heterogeneity; specifically, east of the "Hu-Huanyong line," soybean production advantages are more obvious. Additionally, the study considered the actual planting situation of soybeans and envisaged two scenarios of compound planting and strip planting. The soybean production range in 2030 is expected to be 20.73–22.32 million tons and 21.15–27.55 million tons, with self-sufficiency rates varying from 18.57 to 19.98% and 18.95 to 24.68%, respectively. The research aims to provide a comprehensive understanding of China's soybean industry and its potential trajectories, employing a model combining historical trends, policy analysis, and technological advancements. Results suggest a promising future with strategic adjustments in planting structures. Recommendations emphasize policymakers' prioritization of technological investments and sustainable planting practices to achieve projected production targets. Policy interventions must address challenges tied to resource limitations, trade conflicts, and the ongoing COVID-19 effects, ensuring soybean industry resilience.

KEYWORDS
sustainable, import-dependent agricultural products, production forecast, soybean, China

1 Introduction

The relationship between food production and consumption has become a significant area of research, as it provides valuable insights into the connection between humans and ecosystems. Ecosystems play a crucial role in supplying the goods and services necessary for human survival. However, in recent decades, there has been a rapid increase in the global population, along with the development of socioeconomic conditions and more diverse consumption patterns. Estimations suggest that the global population is projected to reach 11.2 billion by the year 2100 (Khan et al., 2021; Islam et al., 2022). This population growth, coupled with the subsequent increase in resource demand, poses a significant challenge to sustainable agriculture and food security, particularly in the context of climate change and shifting land-use patterns. Consequently, there is intense competition to produce an adequate quantity and quality of food to meet the demands of the growing population (Khan et al., 2021). Furthermore, the COVID-19 pandemic has additional exacerbated food security concerns for many countries, impacting both resident production and international trade. The pressures arising from global climate change, including abiotic and biotic factors, have steadily undermined sustainable agricultural practices, posing substantial threats to worldwide food production (Yadav et al., 2015). As a result, numerous industrialized nations have acknowledged the necessity of embracing contemporary agricultural technology. This is crucial to guaranteeing food security for their expanding populations while also advancing sustainable industries and fostering economic growth simultaneously.

In response to these challenges, researchers are now investigating agricultural diversification as an alternative strategy for developing nations. Given the pronounced and detrimental environmental impact of modern agriculture, which has played a pivotal role in exacerbating climate change, there is heightened scrutiny of the ecological consequences associated with digitally-focused agricultural systems that have been embraced and valued for decades without due consideration for environmental factors (Siamabele, 2021). The current farming techniques, as they currently stand, are unsustainable due to their detrimental effects on the environment and wasteful use of vital resources. Consequently, it becomes imperative to overhaul the foundational assumptions guiding fundamental plant scientific research and the orientation of demand-driven plant breeding, to enable crops to flourish in both typical and resource-constrained conditions. Due to its remarkable adaptability, ability to thrive in diverse environmental conditions, and significant multifaceted influence, the cultivation of soybeans is strongly advocated in these specific contexts. It is worth noting that a handful of nations, including the United States, Brazil, Argentina, India, and China, exert substantial dominance over global soybean production (Pagano and Miransari, 2016; Islam et al., 2022).

Soybeans hold a pivotal role as the most crucial grain and oil crop, with their growth being of utmost importance for both food and oil security (Ma, 2016; Pagano and Miransari, 2016; Wang et al., 2023). In 2020, China acquired 100.33 million tons of soybeans, with imports accounting for approximately 90% of this volume, owing to their high-quality production (Ren et al., 2021). According to projections outlined by Liu et al. (2021), soybean demand is expected to surge to 133 million tons by 2035. This heavy dependence on imports exposes China to various risks, including unstable international political relations, recurrent outbreaks of the novel coronavirus epidemic, catastrophic weather events, and the volatility of import trade policies in soybean-importing nations. Notably, in 2020, 11 countries, most notably Vietnam and Russia, imposed restrictions on the export of agricultural goods, leading to speculations in commodity markets such as soybeans. Furthermore, major soybean-producing nations like the United States and Brazil face the looming threat of reduced production. The global soybean market directly influences the international agricultural products market, thereby affecting domestic soybean supply, overall market growth, animal husbandry, and related industries (Yao et al., 2020).

On a global scale, China's soybean business remains generally unprofitable (Sturgeon et al., 2016). This is primarily due to the combination of low soybean production and high production costs. In 2020, the average production cost of soybeans in China stood at 720.52 yuan per mu, which is double the production cost in the United States and Brazil. However, the yield per unit in China is only three-fifths of that in the United States, and it lacks a pricing advantage over imported soybeans. In 2020, the cost of imported soybeans exceeded 3,200 yuan per ton, while local soybean prices surpassed 5,700 yuan per ton, resulting in a price differential of more than 2,000 yuan per ton between domestic and foreign soybeans. Additionally, the expansion of domestic soybean-growing regions has been modest. From 1995 to 2020, China's average annual growth rate for soybean plantation areas was a mere 0.79%, which is less than one-third of that for maize. Ensuring a consistent soybean supply is a significant responsibility within the agricultural and rural sectors, as places substantial emphasis on the local production capacity of imported agricultural goods (Zhang, 2017). Both the National Agriculture Sustainable Development Plan (2015–2030) and the Central Rural Work Conference of 2021 have underscored the necessity to optimize and transform the agricultural planting structure, increase the cultivation area for soybeans and oilseeds, and promote higher output.

In 2022, Central Document No. 1 took a significant step by strongly endorsing the Soybean Oilseed Capacity Improvement Project. This commitment was further solidified through the issuance of the "Guiding Opinions of the Ministry of Agriculture and Rural Affairs on Ensuring Successful Soybean Oilseed Expansion in 2022." Provinces such as Heilongjiang, Hebei, Shanxi, Jilin, Sichuan, Shaanxi, and others began implementing measures to expand soybean production. These efforts aimed to refine the task of increasing soybean production capacity, clearly indicating the central government's policy direction regarding soybeans. Each province received distinct policy guidance tailored to its production potential. Therefore, it is imperative to comprehend the patterns governing China's soybean production layout, delineate the primary soybean-producing provinces, and enhance the nation's soybean production potential. This strategic approach aligns with the overarching goal of ensuring basic self-sufficiency and absolute food security, holding immense significance in stabilizing China's domestic strategic landscape concerning agriculture and reducing the vulnerabilities associated with international soybean imports. Research on the distribution of agricultural production is relatively extensive and predominantly focuses on two key aspects. Firstly, it investigates shifts in the geographical distribution of various agricultural products, encompassing varieties such as cotton (Feng et al., 2022), vegetables (Wang et al., 2018), peanuts (Moisa et al., 2022), dairy cattle (Chen et al., 2022), and major grain crops (Liu et al., 2019). These studies employ a range of methodologies, including the theory of comparative advantage, comprehensive advantage indices, and concentration coefficients. Secondly, research delves into the factors influencing agricultural production layout, primarily revolving around agricultural and natural resources, regional economic benefits, scientific and technological advancements, and geographic environments (Chai et al., 2019; Yu et al., 2019, 2022; Liu et al., 2020; Chen et al., 2022a).

When examining the soybean industry's layout, some scholars contend that China boasts comprehensive comparative advantages in soybean production, particularly in the Northeast and the Huanghe-Huaihe-Haihe production areas (Xu et al., 2001). Over time, the dominant regions for domestic soybean production have shrunk, and the industry's layout has shifted closer to these dominant areas, resulting in a trend where soybean cultivation area and production have increased in northern regions while yield growth has expanded in southern regions (Wang, 2014). Conversely, some scholars argue that over the past 2 decades, soybean production has exhibited fluctuations and overall growth, forming a spatial pattern characterized by "concentration in the northeast and diffusion in the southwest" (Chen et al., 2022b). Notably, existing studies demonstrate variations in data periods used by scholars, with Wang (2014) and Chen et al. (2022b) focusing primarily on the years from 1978 to 2018 and employing slightly different research methodologies, including qualitative analysis, concentration indices, comprehensive comparative advantage indices, locational entropy, and the Gini coefficient, among others. Given the significant shift in China's soybean policy orientation after 2017, marked by a more pronounced incentive for soybean cultivation (Wang and Si, 2021), it becomes essential to conduct further research to understand the latest evolutionary patterns in China's domestic soybean production dynamics. This aims to capture the changing landscape of soybean production regions and more precisely enhance China's soybean production potential.

The first perspective is centered on maximizing the existing growth potential of grain production, with a primary focus on expanding the capabilities of current grain production methods. This research encompasses a wide scope, including major food-producing nations across the globe (Zhou et al., 2015), countries along the Belt and Road initiative (Zhang et al., 2021), the African region (Marrison and Larson, 1996), and key grain-producing provinces within China (Cao et al., 1995; Yao et al., 2020). Methodologies employed in this context predominantly utilize Geographic Information System spatial tools, the Global Agro-Ecological Zoning method, productivity decay models, and step-by-step revision models that address limiting factors.

The second perspective involves projecting future grain production based on current agricultural conditions, with a particular emphasis on forecasting potential growth in grain production. This research is more China-centric, examining macro-level dynamics (Wu and Wang, 2002), secondary cropping areas (Hu et al., 2002), and individual grain-producing provinces (Lu et al., 2013). Methodologies utilized encompass gray correlation coefficients, linear regression, smoothing indices, autoregression, time series trend forecasting, and empirical extrapolation. Although various methods have been applied by scholars such as Wu and Wang (2002), Wang et al. (2020), Si and Han (2021), and Zhu et al. (2022) to forecast domestic soybean production between 2025 and 2030, existing studies have primarily focused on the national level. However, considering the disparities in production conditions and policy implementation across different provinces, it becomes more meaningful to extend these forecasting results to the provincial level.

Considering the central government's initiative for complex planting expansion of oilseed crops in 2022 and drawing upon the research of Zhu et al. (2022), which emphasizes yield improvement and the expansion of soybean cultivation areas, this study aims to evaluate the development of sustainable agricultural production at the local level in China and its reliance on imported products. To anticipate China's soybean potential, including technical advancements and management model enhancements, and to align these with soybean production, we refine indicator selection and future potential forecasts. This research further segments the 2030 soybean potential forecasts by province, considering production layouts, thereby providing a roadmap for optimizing future arrangements. Such an approach ensures a more comprehensive understanding of China's soybean production potential and guides strategic planning for the future.

To summarize, this paper uses China's inter-provincial panel data from 1995 to 2020 to explore China's soybean production layout and future development potential through soybean production advantage coefficient measurement, scenario hypothesis forecasting, and other research methods. The results of this paper are intended to provide help for regional soybean production layout planning, relevant policy proposals, and practical production guidance, as well as to provide a reasonable analytical framework for research on bean production in other countries.

This paper has four parts, following the introduction. Section 2 shows the methodology and data sources. Section 4 presents the results and discussion, and finally, Section 5 outlines the details conclusions of the study.

2 Theoretical framework

This study seeks to explore the complex interplay of factors influencing soybean production in China and the critical role it plays in ensuring food security. The theoretical framework for this study draws upon key theoretical concepts and principles that provide a comprehensive foundation for understanding the dynamics of soybean production, sustainability, and food security in the Chinese context. Food Security Theory: At the heart of the study lies the concept of food security. Food security, a fundamental principle in agriculture and economics, emphasizes the importance of ensuring that a nation has reliable and stable access to enough nutritious food supply to meet the dietary needs of its population (Maxwell and Smith, 1992; Food and Agriculture Organization, 1996). In the context of soybean production, food security is central, as soybeans are a critical component of the Chinese diet and a primary source of protein. Food security theory guides the assessment of how import-independent domestic soybean production influences the stability and adequacy of China's food supply (Timmer, 2004). Agricultural Sustainability Theory: the study also draws on the principles of agricultural sustainability, which focus on the development and implementation of agricultural practices that are environmentally responsible, economically viable, and socially equitable. These principles underscore the importance of practices that reduce negative environmental impacts, ensure long-term agricultural viability, and promote social equity (Francis et al., 2003; Pretty, 2008). In the context of soybean production, agricultural sustainability theory guides the evaluation of the environmental, economic, and social implications of domestic production. Import-Dependency and Vulnerability Theory: Given China's reliance on imports for soybeans, the study incorporates the theory of import-dependency and vulnerability. Import-dependency theory emphasizes the risks associated with relying on foreign sources for essential agricultural products. Vulnerability theory explores the susceptibility of a nation's food supply chain to external shocks, including resource limitations, international trade conflicts, and pandemics (Barrett and Li, 2002; Zhu et al., 2023). These theories inform the assessment of China's vulnerability to shifts in international risk factors and the implications for its food security. By applying these theories and concepts, the study aims to address the critical questions surrounding sustainability, food security, and import dependency. The framework informs the research methodology, data analysis, and policy recommendations, contributing to a comprehensive understanding of the sustainable future of domestic soybean production in China and its implications for food security.

3 Methodology and data sources

3.1 Evaluating soybean industry concentration measurements at the national level

To measure the overall changes in the layout of soybean production areas in China, the concentration coefficient measurement method is used to reflect the regional distribution characteristics of soybeans to a certain extent. The higher the concentration factor of the production area, the more concentrated soybean planting is in a few areas. Drawing on the method of Liu et al. (2002), the following steps were taken.

$$\mathrm{A} = \frac{SAi}{SA} \tag{1}$$

where A is the grouping of the proportion of soybean sown area in each province of China to the soybean sown area in China, divided into six groups of less than 1, 1–3%, 3–5%, 5–7%, 7–10%, and more than 10%; SAi is the soybean sown area in each province in that year, and SA is the total soybean sown area in China in that year.

$$P_i = \frac{PAi}{PA} \tag{2}$$

P_i represents the number of provinces in each group as a proportion of the total number of provinces after being divided into six groups; PAi represents the number of provinces in each group; PA represents the overall provinces in all groups.

$$Y_i = \frac{AAi}{AA} \tag{3}$$

Y_i represents the sum of the soybean sown area of the provinces present in each group as a proportion of the total sown area of the whole group; AAi represents the sum of the soybean sown area of the provinces present in each group, and AA represents soybean sown area in China.

$$U_i = \sum Yi \tag{4}$$

U_i represents the cumulative share of the sown area in each group.

$$V_i = U_{i-1} + U_i \tag{5}$$

V_i represents the cumulative soybean sown area share for each subgroup added two by two according to rank.

$$S_i = V_i \times P_i \tag{6}$$

S_i represents the multiplication of each group V_i with P_i.

$$G = S_i / 10000 - 1 \tag{7}$$

G represents the soybean production concentration factor. A larger G for each year represents a higher degree of concentration.

3.2 Measurement of production concentration advantages by the province in China

The layout of soybeans by the province in China is observed from the perspective of soybean production, and a province is defined as a major soybean-producing province if its soybean production in that period accounts for more than 1% of China's soybean production in the same period.

$$C_i = Y_{it} / Y_t \tag{8}$$

C_i represents the concentration of production in each province, Y_{it} is the soybean production in a province in a given period, and Y_t is the national soybean production in a given period.

3.3 Soybean regional scale comparative advantage measurement

The scale comparative advantage index can reflect the scale and specialization of soybean production in a given region from the perspective of the sown area to observe the layout of soybeans in each province in China, which facilitates the observation of inter-province differences.

$$SI_{ib} = \frac{\left(GS_{ib} / GS_{ig} \right)}{\left(GS_b / GS_g \right)} \quad (9)$$

The formula SI_{ib} denotes the comparative advantage index of soybean cultivation scale in region *i*, GS_{ib} denotes the area of soybean cultivation in region *i*, GS_{ig} denotes the area of all crops cultivated in region *i*, GS_b denotes the area of soybean cultivation in the country, and GS_g denotes the area of crops cultivated in the country. $SI_{ib} > 1$ means that region *i* has a scale advantage in producing soybeans and less than 1 which means that it does not have a scale advantage.

3.4 Production potential indicators measurement

The main indicators in the study of production potential are self-sufficiency measurements, yield forecasts, and the choice of a banded composite model.

$$P = \left(S + F \right) / D \quad (10)$$

P is the soybean self-sufficiency rate, *S* is China's domestic supply, *D* is China's domestic demand, and *F* is the value of production growth resulting from different scenario assumptions, with China's domestic supply and demand both based on the year 2020.

$$Q = Q_s + Q_f \quad (11)$$

Q represents the production forecast, Q_s represents the baseline domestic soybean production in 2020, and Q_f represents the increase in production under different scenarios.

$$\text{Strip composite mode 1}: M = S / C \quad (12)$$

Where *S* is the total area of technical transformation of the 16 provinces of China in 2022 for the banded composite cropping pattern and *C* is the total area of maize sown in the 16 provinces in the base year (2020).

$$\text{Strip composite mode 1}: M_2 = \frac{S_2}{\text{C}} \quad (13)$$

S_2 is the planned strip composite planted area in 2025, and *C* is the total maize sown area in 16 Chinese provinces in the base year (2020).

3.5 Data source

The data on soybean density and competitive advantages of scale came from the China Statistical Yearbook for 1996–2021, which also included forecasts for soybean production, supply, and demand for soybeans for 2020 as the base year from the Food and Agricultural Organization (FAO) database, information on the area under strip planting in 2022 from the Ministry of Agriculture and Rural Affairs of China, and online data from provincial agricultural and rural departments.

4 Results and discussion

4.1 Layout of soybean production in China and its changing characteristics

4.1.1 Regional concentration of soybean production in China

China's soybean production is moving from decentralized to centralized, and the year 2000 became a watershed of change (Figure 1). Before 2000, the soybean planting area in China was relatively scattered. After that, the soybean planting area showed a trend of increasing concentration. Especially after 2018, the soybean concentration increased sharply and reached a peak in 2020. In 1995, the concentration coefficient was 0.49. From 1995 to 2020, the soybean concentration increased to the concentration in three stages: First, China's soybean production was relatively scattered from 1995 to 1999, and the concentration coefficient was small but remained unchanged at around 0.48. Second, from 2000 to 2009, the concentration coefficient increased rapidly, from 0.54 in 2000 to 0.64 in 2009. From 0.54 in 2000 to 0.64 in 2009, the average annual growth rate was 2.04%. Third, from 2010 to 2020, the concentration coefficient increased steadily, from 0.62 in 2010 to 0.67 in 2020, with an average annual growth rate of 0.88%. After 2018, the growth rate was even faster, reaching 3.84%.

4.1.2 The evolution trends of soybean production layout in China

To examine the yield changes in China's soybean-producing provinces, the concentration index is used for analysis in Table 1. The concentration index refers to the proportion of soybean production in a region to China's production in the same period. According to the method of Liu (Chen et al., 2022b), relevant provinces with a soybean production concentration greater than 1% were screened out, and the comparisons were made according to the time series to observe the comparative changes in soybean production provinces.

From the analysis of soybean production areas, the top 10 soybean-producing provinces (concentration index >1) (Figure 2) gradually evolved from the original Northeast and Huanghe-Huaihe-Haihe production areas to a multi-point layout of Northeast, Huanghe-Huaihe-Haihe, Southwest and middle and lower reaches of Yangtze River production areas, and the dominant main production areas are developing into a diversified trend. Before 2005, the top 10 provinces in terms of concentration were mainly dominated by Northeast and Huanghe-Huaihe-Haihe production areas, but after 2005, the dominance of provinces in the Southwest and middle and lower reaches of Yangtze River production areas has become more obvious. For example, Sichuan Province in the southwest production area rose from tenth place in 1995 to third place in 2020; Yunnan Province, which did not enter the range of major soybean-producing provinces in 1995, rose to tenth place in 2020. The concentration of some provinces in the Northeast and Huanghe-Huaihe-Haihe

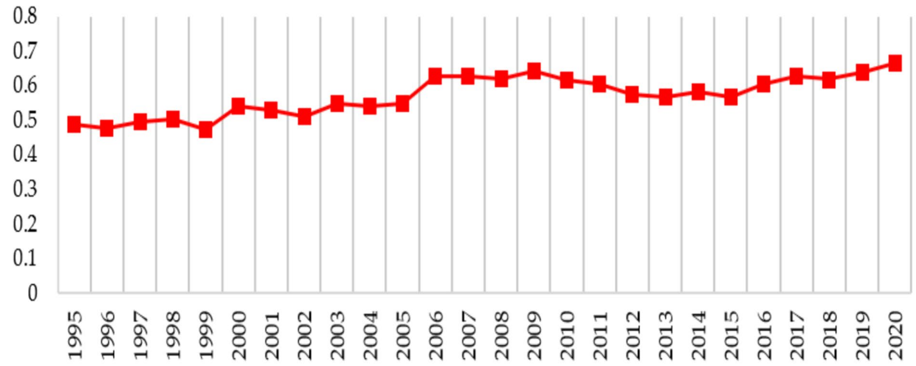

FIGURE 1
Change in the coefficient of concentration of sown area for soybean production in China, 1995–2020. Data source: China Statistical Yearbook (1996–2021).

production areas has dropped significantly, such as Liaoning Province from ninth place in 1995 to thirteenth place in 2020; and Hebei Province from fourth place in 1995 to 16th place in 2020.

Although the regions are diversified, from the perspective of the provincial level, the trend of concentration of advantageous production areas is obvious. From 1995 to 2020, the concentration ratio of provinces greater than 1% did not change much, but the concentration ratio of the top 10 provinces increased. The concentration ratio of the top 10 provinces increased from 78.40% in 1995 to 86.53% in 2020. The fastest provinces are Heilongjiang and Inner Mongolia. The proportion of the two provinces has risen from 31.65 and 3.89% in 1995 to 46.95 and 11.98% in 2020, respectively.

4.1.3 Analysis of the comparative advantages of regional scale of soybean production in China

To analyze the layout of soybean production in China from the perspective of the sown area in each province, the scale comparative advantage coefficient was obtained using the ratio of the sown area in each province to the national sown area, and if the coefficient is greater than the 1, it means that the degree of soybean production specialization in that region is higher than the national average in the same period. $SI_{ib} > 2$, $2 > SI_{ib} > 1$, $1 > SI_{ib} > 0.5$, and $SI_{ib} < 0.5$ correspond to obvious and strong comparative scale advantages and weak and obvious comparative scale disadvantages, respectively. Chinese provinces with comparative advantage in soybean scale are mainly concentrated in the spring soybean-producing areas in the Northeast and the summer soybean-producing areas in the Huanghe-Huaihe-Haihe, with a tendency to spread to the middle and lower reaches of the Yangtze River over time, and the number of provinces with scale advantage is decreasing year by year. The trend is like that of production concentration, so the concentration coefficient and the scale comparative advantage index have some consistency in reflecting the regional layout of soybean production in China.

From the perspective of Chinese provinces, except for provinces with a clear scale disadvantage ($SI_{ib} < 0.5$) for soybeans, all other scale-advantaged provinces are around the "Hu Huanyong line" with interannual variation and a tendency to the right. Not many provinces are in the obvious scale advantage area, mainly in the traditional grain-producing areas (Heilongjiang, Inner Mongolia, Jilin, and Anhui). Soybean production has been at a clear scale comparative disadvantage in relatively remote areas such as Xinjiang, Tibet, Hainan, Yunnan, and Gansu, which are more closely related to natural condition factors; likewise, Beijing, Jiangsu, Guangdong, Chongqing, and Shanghai, which are also at a clear scale comparative disadvantage, are all non-traditional grain-producing provinces whose urban positioning, agricultural development goals, and natural state are not It is worth noting that although Sichuan Province does not have an obvious scale comparative advantage, the scale comparative index has improved significantly, and it is also a key area for soybean ribbon complex planting transformation in recent years.

4.2 Production potential forecast for China's major soybean-producing provinces

4.2.1 The main reference basis for scenario setting

Figure 3 shows the information extracted from the "Soybean Revitalization Plan," "14th Five-Year Plan," and the development goals and positioning of future planting areas, yield level, and technological enhancement proposed in the Central Government's No. 1 document on soybean development in recent years were used as the main basis for soybean potential estimation in this study on the pattern of layout changes.

4.2.2 Main parameters and basis of scenario-set indicators

As the "14th Five-Year Plan" period is an important window for promoting the modernization of agriculture and rural areas, it is important to increase the changes in agricultural technology and organizational management to enhance the overall modernization of agriculture (Table 2). Combining the development of China's soybean industry, the potential projections for each major province of soybean in China in 2030 were made by combining available information with actual fitted scenario setting parameters under two scenarios of technology level upgrading and banding compound planting and management technology improvement utilization.

TABLE 1 China's main soybean-producing provinces and production concentration from 1995 to 2020 Unit: %.

1995		2000		2005	
Provinces	Production concentration	Provinces	Production concentration	Provinces	Production concentration
Heilongjiang	31.65	Heilongjiang	29.21	Heilongjiang	38.51
Shandong	9.11	Jilin	7.81	Inner Mongolia	8.00
Henan	7.90	Henan	7.51	Jilin	7.96
Hebei	5.82	Shandong	6.79	Anhui	5.43
Jilin	5.80	Anhui	5.94	Shandong	3.98
Anhui	4.76	Inner Mongolia	5.57	Henan	3.55
Inner Mongolia	3.89	Jiangsu	4.35	Sichuan	3.22
Jiangsu	3.40	Hebei	4.08	Jiangsu	2.98
Liaoning	3.06	Liaoning	3.12	Hubei	2.66
Sichuan	3.01	Hubei	2.97	Hebei	2.59
Hubei	2.93	Hunan	2.78	Hunan	2.45
Hunan	2.82	Sichuan	2.43	Liaoning	2.35
Jiangxi	2.20	Guangxi	2.36	Guangxi	1.96
Guangxi	2.18	Shanxi	2.33	Zhejiang	1.80
Shanxi	1.63	Zhejiang	1.84	Shanxi	1.59
Shaanxi	1.52	Jiangxi	1.68	Shaanxi	1.50
Zhejiang	1.40	Shaanxi	1.44	Xinjiang	1.42
Fujian	1.27	Fujian	1.33	Guangdong	1.15
Guangdong	1.22	Guangdong	1.21	Fujian	1.12
Guizhou	1.02	Guizhou	1.17	Jiangxi	1.09
		Xinjiang	1.14	Chongqing	1.08
				Yunnan	1.06
Total	96.59	Total	97.07	Total	97.46
2010		**2015**		**2020**	
Provinces	**Production concentration**	**Provinces**	**Production concentration**	**Provinces**	**Production concentration**
Heilongjiang	39.93	Heilongjiang	40.33	Heilongjiang	46.95
Inner Mongolia	9.69	Inner Mongolia	10.25	Inner Mongolia	11.98
Anhui	6.82	Anhui	7.44	Sichuan	5.17
Jilin	5.85	Sichuan	6.22	Henan	4.77
Henan	5.45	Jiangsu	3.80	Anhui	4.74
Sichuan	3.96	Henan	3.78	Jilin	3.28
Jiangsu	3.78	Yunnan	3.31	Shandong	2.83
Shaanxi	2.91	Shandong	2.66	Jiangsu	2.65
Shandong	2.44	Jilin	2.55	Yunnan	2.37
Guizhou	2.07	Hubei	2.47	Hubei	1.81
Yunnan	2.00	Jiangxi	1.88	Hunan	1.59
Hubei	1.80	Zhejiang	1.79	Jiangxi	1.42
Liaoning	1.71	Hunan	1.78	Liaoning	1.22
Hebei	1.51	Chongqing	1.52	Shaanxi	1.21
Hunan	1.47	Shaanxi	1.28	Guizhou	1.14
Jiangxi	1.18	Hebei	1.24	Hebei	1.14
Chongqing	1.12	Shanxi	1.18	Zhejiang	1.11
Guangxi	1.03	Liaoning	1.09	Shanxi	1.06

(Continued)

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TABLE 1 (Continued)

1995		2000		2005	
Provinces	Production concentration	Provinces	Production concentration	Provinces	Production concentration
		Guangxi	1.09	Chongqing	1.03
		Guizhou	1.08		
		Gansu	1.02		
Total	94.73	Total	97.74	Total	97.44

Data source: calculated from relevant data in China Statistical Yearbook 1996–2021.

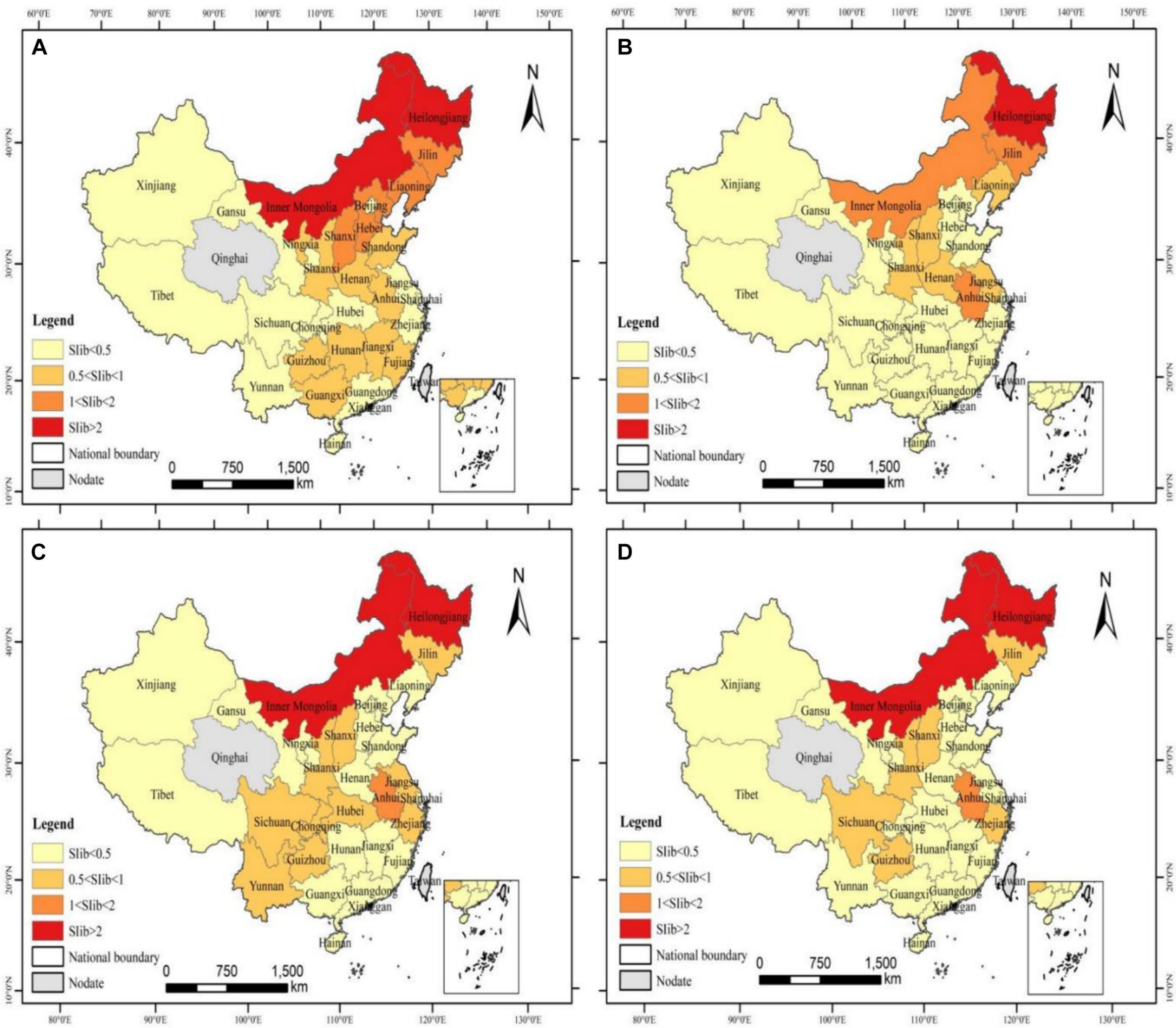

FIGURE 2
Regional map of comparative advantages of scale (*a* = 1995; *b* = 2008; *c* = 2017; *d* = 2020).

4.2.3 Scenario setting and production forecast (2030)

The first scenario involves technological development. "Improving yields through technological development is the engine of domestic soybean production growth in China during the 14th Five-Year Plan but given that technological advances in domestic soybean production in China do not show an accelerating trend over time, the growth rate of soy-bean in 2030 should not be set too high when forecasting production," says the report. Referring to the method of Zhu (Wang, 2014) for extrapolating the average annual growth rate of yields to predict future soybean yield levels and setting the average annual growth rates of domestic Chinese and

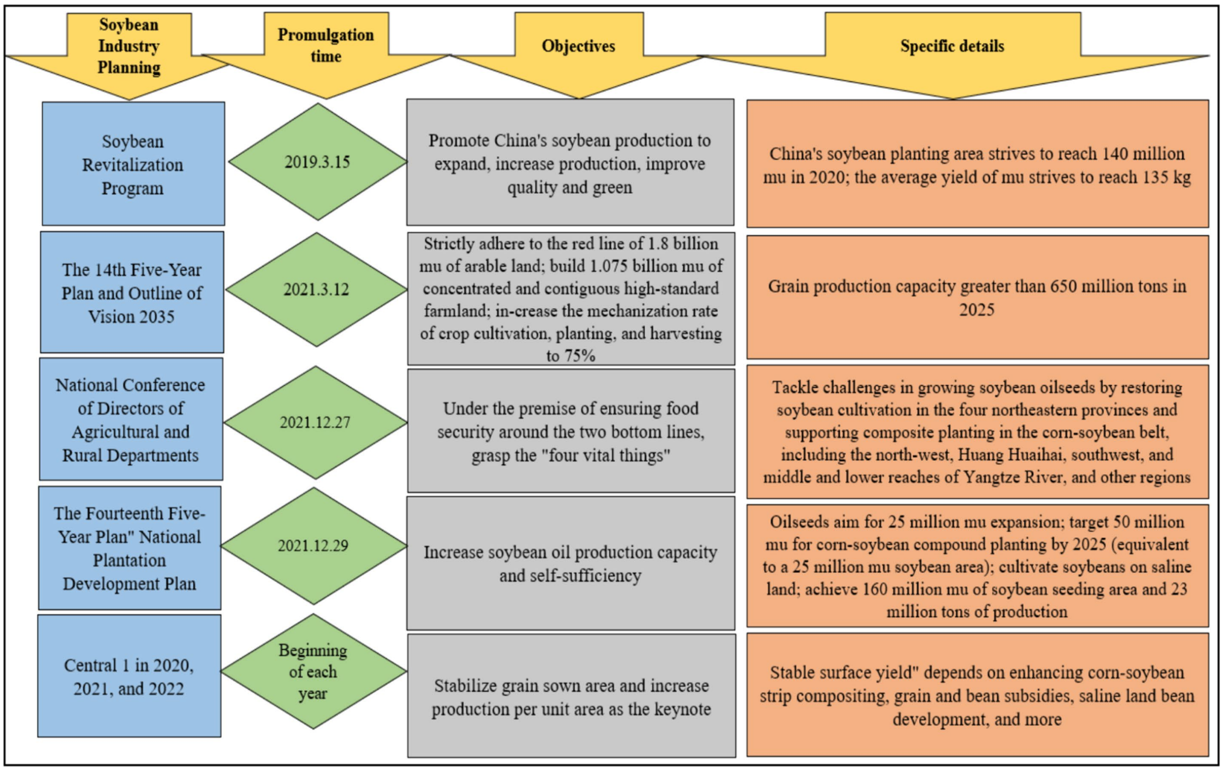

FIGURE 3
Soybean industry development forecast main reference bases and sources. Data source: General Office of the Ministry of Agriculture and Rural Affairs, the Central People's Government of the People's Republic of China, and other websites.

Indian soybeans from 2004 to 2020 as low and medium, respectively, and referring to Liu et al. (2002) to set their predicted values to the high growth rate value of this scenario, which is more in line with the domestic soybean development. The value of soybean production increase in each province after the technological level improvement with the same soybean sowing area in 2020 is shown in Table 3.

Considering the average annual growth rate in 2020 as our reference point, China's domestic soybean production is projected to reach 20.7257, 21.0787, and 22.0323 million tons by 2030, respectively (refer to Table 4). This trajectory indicates self-sufficiency rates of 18.57, 18.89, and 19.98%, respectively. Regardless of growth rates, it is noteworthy that the top five provinces Heilongjiang, Inner Mongolia, Sichuan, Henan, and Anhui accounted for a significant 73.6% of total national production in the base period. The strategic development of the soybean industry in these provinces holds pivotal importance for future soybean cultivation in China, particularly if technological advancements are leveraged effectively. The technological model for planting and managing the soybean-corn ribbon complex has been upgraded in scenario 2. For China's domestic food security in the future, expanding soybean planting in the northeast and promoting corn-soybean ribbon complex planting in the northwest, the Huanghe-Huaihe-Haihe zone, the southwest, and the middle and lower reaches of the Yangtze River become crucial strategic directions. The Chinese Ministry of Agriculture and Rural Affairs arranged the promotion of 15.5 million mu of ribbon composite planting model in 16 provinces (municipalities and districts) countrywide in 2022 as one of the major models to enhance soybean production increase from 2021 onward. Therefore, scenario 2 focuses on measuring the potential contribution of maize ribbon composite to the growth of soybean domestic production potential in each province in China, and at this stage, the promotion of ribbon composite technology is mainly in 16 provinces outside the non-northeastern production areas and is based on the spirit of the 2021 China Central Rural Work Conference and the 14th Five-Year Plan for National Plantation Development. Technology promotion requirements. Based on the existing extension area in 2022, the low extension ratio in 2030 is set at 3.9%; the median extension ratio in the 14th Five-Year Plan is set at 12.59%; and the high extension ratio is set at 20%, to examine the yield that can be released in each province in 2030 shows in Table 4.

According to Scenario 2, where the future penetration rate of the belt composite technology is different in each province, taking 2020 as the benchmark, China's domestic soybean production in 2030 will be 21.1494, 24.618, and 27.5457 million tons, respectively. The self-sufficiency rates were 18.95, 22.04, and 24.68%, respectively. If the belt compound planting technology continues to be developed in the future, the production share of the top five regions (Inner Mongolia, Sichuan, Henan, Anhui, and Shandong) in which the belt compound technology is adopted will increase from 29.49 to 31.36%, 34.69 and 34.69% of the original benchmark. 36.86%. If the Northeast region continues to increase the soybean planting area, China's domestic soybean production will continue to increase in the future.

TABLE 2 Soybean industry scenario.

Parameter indicators	Years	Value	Setting basis
Soybean acreage (study baseline value)	2020	Sown area, mu yield, and production by province; domestic demand and supply in China	Assumed basis
The average annual growth rate of soybean 1	2020–2030	0.56%	Estimated average annual soybean growth rate, 2004–2020 (projected by extrapolating inter-annual data)
The average annual growth rate of soybean 2	2020–2030	0.73%	India soybean CAGR 2004–2020
The average annual growth rate of soybean tree	2020–2030	1.3%	Liu et al. (2002) predicted
Band composite mode boost 1	2030	3.9%	Sixteen banded composite technology planting provinces maintain their mission targets in 2022
Band composite mode boost 2	2030	12.59%	Maintain the planned promotion of 50 million mu in 2025
Band composite mode boost 3	2030	20%	Combined with the fourteenth 5-year plan reasonably proposed
Soybean yield in the banded composite model	2030	100 kg	Data integration

Data source: Chinese provincial government websites, FAO, and literature.

TABLE 3 Soybean production by Province in China under different growth rates in 2030.

Provinces	Baseline production (million tons)	Low (0.56%)	Median (0.73%)	High (1.3%)
Heilongjiang	920.29	973.14	989.72	1047.17
Inner Mongolia	234.74	248.22	252.45	267.10
Sichuan	101.25	107.07	108.89	115.21
Henan	93.42	98.79	100.47	106.30
Anhui	92.94	98.28	99.95	105.75
Jilin	64.23	67.92	69.08	73.09
Shandong	55.49	58.68	59.68	63.14
Jiangsu	51.93	54.91	55.85	59.09
Yunnan	46.4	49.06	49.90	52.80
Hunan	31.16	32.95	33.51	35.46
Jiangxi	27.75	29.34	29.84	31.58
Liaoning	23.9	25.27	25.70	27.20
Shaanxi	23.64	25.00	25.42	26.90
Guizhou	22.35	23.63	24.04	25.43
Hebei	22.31	23.59	23.99	25.39
Zhejiang	21.75	23.00	23.39	24.75
Shanxi	20.78	21.97	22.35	23.65
Chongqing	20.22	21.38	21.75	23.01
Guangxi	15.44	16.33	16.60	17.57
Fujian	9.47	10.01	10.18	10.78
Guangdong	9.1	9.62	9.79	10.35
Xinjiang	5.22	5.52	5.61	5.94
Ningxia	1.65	1.74	1.77	1.88
Other provinces	44.57	47.13	47.93	50.72
National total	1960	2072.57	2107.87	2230.23

Data source: collated and measured.

TABLE 4 Growth of domestic soybean production in China under different banded composite technology promotion areas, 2030.

Provinces	Base value (2020)	Low 3.90%	Median 12.59%	High 20%	Whether or not to promote
Inner Mongolia	234.74	257.11	306.95	349.46	Yes
Sichuan	101.25	112.01	135.99	156.43	Yes
Henan	93.42	115.76	165.52	207.96	Yes
Anhui	92.94	100.16	116.26	129.98	Yes
Shandong	55.49	78.14	128.6	171.62	Yes
Jiangsu	51.93	54.91	61.56	67.22	Yes
Yunnan	46.4	56.94	80.44	100.48	Yes
Hunan	31.16	33.41	38.42	42.69	Yes
Shaanxi	23.64	30.54	45.91	59.02	Yes
Guizhou	22.35	25.28	31.82	37.4	Yes
Hebei	22.31	42.3	86.84	124.82	Yes
Shanxi	20.78	30.97	53.68	73.05	Yes
Chongqing	20.22	22.8	28.55	33.45	Yes
Guangxi	15.44	18.93	26.71	33.35	Yes
Gansu	8.16	14.01	27.06	38.18	Yes
Ningxia	1.65	3.54	7.74	11.33	Yes
Heilongjiang	920.29	920.29	920.29	920.29	No
Jilin	64.23	64.23	64.23	64.23	No
Jiangxi	27.75	27.75	27.75	27.75	No
Liaoning	23.9	23.9	23.9	23.9	No
Zhejiang	21.75	21.75	21.75	21.75	No
Fujian	9.47	9.47	9.47	9.47	No
Guangdong	9.1	9.1	9.1	9.1	No
Xinjiang	5.22	5.22	5.22	5.22	No
Others	36.41	36.41	36.41	36.41	No
Total	1960	2114.94	2460.18	2754.57	——

5 Conclusion, policy implications, and limitations

5.1 Conclusion

This research reveals a growing concentration of soybean production in China, driven by limited domestic arable land resources and a heavy reliance on imports. China's soybean planting concentration has steadily increased since 1995, particularly after 2000, with the concentration coefficient of soybean planting area consistently exceeding 0.5. This shift reflects a transition from dispersed to aggregated domestic soybean planting. The scale-based comparative advantages in soybean distribution in China align closely with concentration calculation results. Based on the scale comparative advantage index, regions like Heilongjiang and Inner Mongolia have maintained a clear scale-based comparative advantage for an extended period, particularly Heilongjiang, where the scale comparative advantage index consistently surpasses five. In recent years, provinces like Anhui and Zhejiang, situated in the Huanghe-Huaihe-Haihe region, have also exhibited strong comparative advantages in scale. In the current phase, the issue of food security has evolved from a problem of insufficient supply to an imbalanced planting structure, particularly concerning soybean production. Accelerating the structural reform of the agricultural supply side, expanding soybean cultivation, and forecasting future soybean planting potential within the existing framework are essential steps to ensure national food security in the new era. Scenario analysis, considering advancements in technical capabilities and the adoption of strip compound planting methods, indicates that China's domestic soybean self-sufficiency rate will increase to varying degrees. The highest self-sufficiency rate is projected to reach 19.98 and 24.68%, respectively, depending on the model used. With additional incentives for expanding soybean production in Northeast China, it is plausible that the domestic soybean self-sufficiency rate could reach 30% by 2030.

Against the backdrop of the current macro-food concept, structural contradictions in China's food supply and demand have gradually emerged, with the structure of food production lagging behind the continuously upgrading consumption structure, which is highlighted by the fact that the supply of soybeans is mainly dependent on the international market, which has become a risk to China's food security. Although China's soybean is faced with low yields and slow growth, unstable planting areas, and a mismatch between the supply and demand structure of the "triple dilemma," but still has a certain potential to increase production space. This paper on the soybean production layout and future production potential analysis can better clarify the domestic soybean production status quo, at the same time on the future production of soybean to provide scientific guidance, and further promote China's soybean supply and demand balance, national food security and regional human well-being enhancement.

5.2 Policy implications

The study underscores the need for structural reforms in China's agricultural sector, with a focus on the soybean production system. Policies should be devised to encourage a more balanced and distributed planting structure, moving away from the current trend of concentration. This might involve incentivizing soybean cultivation in regions that have the potential for increased production. To enhance national food security, policies should promote the diversification of soybean planting regions. Emphasizing the development of soybean cultivation in provinces beyond the traditional strongholds like Heilongjiang and Inner Mongolia can contribute to a more resilient and distributed supply chain. The study suggests that advancements in technical capabilities and the adoption of innovative planting methods can positively impact soybean self-sufficiency. Policymakers should consider incentivizing the adoption of these technologies by farmers and investing in research and development to improve soybean productivity. The shift like food security challenges from insufficient supply to imbalanced planting structures calls for long-term planning. Policies should focus on forecasting future soybean planting potential and adapting to changing circumstances to ensure a steady and secure domestic soybean supply.

5.3 Limitations of the study

The study's scenario analysis relies on the assumption that factors influencing soybean production, such as technological advancements and planting methods, will remain relatively stable. In reality, external factors like climate change, market dynamics, and policy shifts could introduce uncertainties that may impact the accuracy of projections. The study simplifies the agricultural system by focusing on soybean production concentration and comparative advantages. However, the broader agricultural landscape involves multifaceted interactions and dependencies. The study may not fully capture the complexities of these interrelationships. The study primarily addresses domestic factors influencing soybean production, but it may not fully account for global market dynamics and trade dependencies. Changes in international markets and trade agreements could significantly impact China's soybean self-sufficiency. The study primarily emphasizes economic and technical dimensions, neglecting the potential social and environmental ramifications of expanding soybean cultivation. Policies formulated from this research ought to integrate considerations for environmental sustainability and the social welfare of local communities. Although the study acknowledges the necessity for structural reforms, it lacks specific policy recommendations. Researchers may require further investigation and consultation to devise detailed and impactful policy measures based on the study's findings. By addressing these shortcomings and capitalizing on the policy implications, a more holistic and efficient strategy can be developed to bolster soybean production and uphold food security in China.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

WK: Writing – original draft, Software, Formal analysis, Data curation, Conceptualization. MW: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. NK: Writing – review & editing, Visualization. JL: Writing – review & editing, Software, Formal analysis. DH: Writing – review & editing, Visualization, Supervision, Resources, Project administration, Investigation, Funding acquisition. HZ: Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Investigation, Funding acquisition, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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