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Study on soybean potential productivity and food security in China under the influence of COVID-19 outbreak

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HIGHLIGHTS

- Potential productivity of soybeans is high.
- There is tradeoff between soybean production and food security in China.
- China has different short- and long-term strategies to ensure sustainable supply of soybeans.

GRAPHICAL ABSTRACT

ABSTRACT

The COVID-19 outbreak that became a global pandemic in early 2020 is starting to affect agricultural supply chains and leading to a rapid rise in global food prices. As many grain exporting countries announced a ban on grain exports, food security issues in China have attracted a significant international attention. Based on the Suitability Distribution Model and Soybean-Cereal Constraint Model, we explored the relationship between soybean production potential and food security. We calculated that the soybean potential planting area in China is 164.3 million ha. If the outbreak prevents China from importing soybeans, soybean planting area will need to be increased by 6.9 times to satisfy the demands. In the meantime, cereal self-sufficiency rate will drop to 65.4%, which will greatly affect food security. Each additional unit of soybean production will reduce 3.9 units of cereal production, and 1% increase in the self-sufficiency rate of soybean will result in a 0.63% drop in the self-sufficiency rate of cereal. Without sacrificing the self-sufficiency rate of cereal, the self-sufficiency rate of soybean is limited to 42%. Consequently, China will still need to import more than 68% of the current import volume of soybean. Although in the short term, the outbreak will not affect food security in China, as soybean imports decrease, insufficient supply of soybeans will affect people's quality of life. To prevent the impact of the COVID-19 outbreak, China should increase soybean stocks and strengthen international cooperation. In the long term, increasing the self-sufficiency rate is a fundamental solution to solving soybean import dependency. The key to increasing soybean cultivation is by making soybean cultivation profitable and by building a sustainable soybean planting chain.

1. Introduction

The novel coronavirus (COVID-19) that has infected more than 3 million people and killed hundreds of thousands globally (WHO, 2020) have pushed countries to implement strict control measures. Yet these measures also affect global supply chains by slowing down production and transport activities, causing rapid increases in global food prices. To make things worse, some countries have announced export bans to ensure domestic stability and food security. Vietnam was the first country that officially announced suspension of its rice export (Vietnam customs, 2020). Other countries such as Russia, Thailand, and Serbia have also proposed temporary food protection measures.

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As the world’s largest food consumer, China has different rates of food self-sufficiency. Although there will not be any food security problems in the short term (i.e., China has a very high rate of cereal sufficiency), China imported 38% of its soybean demands from the United States (US) and 45% from Brazil (Fig. 1). But the COVID-19 outbreak is extremely serious in soybean-producing countries, including the US, Brazil, and Argentina, potentially threatening China’s soybean security.

China is the world’s largest soybean consumer and importer (Yao, 2020) and China considers soybean an important food crop, oil crop and feed source (McFarlane and O’Connor, 2014). Yet the “Giving Priority to Major Grains” policy discourages Chinese farmers to plant soybeans (Trac et al., 2013). Therefore, ensuring sustainable soybean supply in China is one of the most important challenges brought by the COVID-19 outbreak. Many scholars have conducted in-depth research on soybean problem in China, such as soybean yield level, price and benefits factors (Qiang et al., 2012; Yang, 2014; Guo, 2017; Xiao and Du, 2019), and more recently the influence of Sino-US trade friction (Wang, 2018; Fang, 2019; Xiao and Yang, 2019). Studies suggested that China should adjust its import structure (Teng et al., 2018; Pan, 2019), and increase soybean supply, as the government proposed soybean revitalization plan and subsidized soybean farmers in 2019 and 2020. However, there will be competing land uses with cereals and it will have impacts on food security. As the world’s supply chain is likely to be adversely impacted by COVID-19 outbreak, it is necessary to quantify the trade-off between soybean production potential and food security. This study used Soybean Suitability Distribution Model to study the potential productivity of soybeans, and constructed the Soybean-Cereal Constraint Model to explore the potential impacts that might arise from increasing soybean cultivation on food security if agricultural imports are hampered by the outbreak. Using trade-off analysis of soybean production and food security, this article aims to provide a reference for soybean sustainable development strategy and food security research in China.

2. Materials and methods

2.1. Materials

Data on precipitation, accumulated temperature, land-use and administrative regionalization of China were obtained from the database of the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/). The accumulated temperature data were selected from the Chinese meteorological background dataset with an annual accumulated temperature ≥1900°C when the average daily temperature ≥10°C. The land use dataset was obtained from the remote sensing monitoring database of the Chinese land-use status in 2015. The average May temperature data were obtained from the Chinese meteorological data network (https://data.cma.cn/).

Data on planting area, production, yield and earning of various crops in China were obtained from the China rural statistical yearbook. Crops that were observed included rice, wheat, corn, barley, sorghum, buckwheat and oats. Soybean import and export data were obtained from the United Nations commodity trade statistics database, the General Administration of Customs of China and the key agricultural products market information platform (http://zdscxx.moa.gov.cn:8080/misportal/public/agricultureIndexRedStyle.jsp). Data on soybean production by country (2000–2018) were obtained from the Food and Agriculture Organization of the United Nations (FAO). Data on the COVID-19 outbreaks in countries around the world were obtained from the World Health Organization (WHO).

2.2. Methods

2.2.1. Soybean suitability distribution model

In this paper, land-use type, precipitation, annual accumulated temperature and growing period temperature were used as the indicators to evaluate the suitability of soybean planting areas in China. ArcGIS 10.2 was then used to overlay the evaluation results of those indicators. The limit method was applied according to the following necessary conditions for soybean planting and growth (Pan, 1984; Yang et al., 2009; He, 2011; Yang et al, 2014; He et al., 2020).

Land-use type has a significant effect on soil moisture content, organic matter and other physical and chemical properties. Because soybean can be planted in both paddy fields and dry lands, cultivated land was classified as a suitable land-use type for soybean cultivation.

Water is an essential factor for the growth and development of soybean. Because precipitation is an important source of water for soybean production, soybean planting area tends to decrease with decreasing precipitation. An early study suggested that without irrigation, it would be difficult to plant soybeans in areas having an annual precipitation of <250 mm (e.g., Northwest China) (Pan, 1984). Therefore, an area was considered suitable for soybean cultivation in this paper if it had a minimum annual precipitation of 250 mm.

Because low temperatures can delay flowering, ripening and even growth, areas that can be planted with soybean are also restricted. In this study, we limited the areas that have an average daily tempera-
ture of ≥ 10°C, an accumulated temperature above 1900°C to be suitable for soybean cultivation as suggested by two earlier studies (He, 2011; Yang et al., 2014).

In addition, the optimum temperature in which soybean can grow is limited between 12°C and 40°C (He et al., 2020). Therefore, the minimum temperature threshold for spring-planted soybeans in northern China was set at 12°C, which usually happens from late April to early May (Yang et al., 2009; He et al., 2020). As the average monthly temperature does not typically exceed 40°C during soybean growing season, the upper temperature threshold was not set in the evaluation system. Using the average May temperature at each climate station in China, the spatial distribution map of temperature suitability during soybean growing period was developed using the kriging interpolation method in the ArcGIS spatial analysis function.

2.2.2. Soybean remaining planting potential

The soybean remaining planting potential (SRP) is the area of farmland where soybean can be grown in addition to normal cereal cultivation. We used the assumption that all cereals can be grown on farmland, and that cereal production is a priority. In the remaining farmland, the part suitable for planting soybean is the SRP (Fig. 2a). In order to maximize the SRP, cereals are preferentially planted on farms that are not suitable for soybean cultivation (Fig. 2b). SRP can be calculated using the following formula:

\[ S_{RP} = \begin{cases} \text{A}_{S} \ (W \ hen \ C + \text{A}_{S} \leq \text{A}_{F}) \\ \text{A}_{F} - C \ (W \ hen \ C + \text{A}_{S} > \text{A}_{F}) \end{cases} \]  

In the formula, \( S_{RP} \) is SRP, \( \text{A}_{S} \) is the suitable total area of soybean, \( \text{A}_{F} \) is the total area of farmland, and \( C \) is the cereal planting area. \( \text{A}_{S} \) is calculated from the soybean suitability distribution model. Using this formula, the calculated soybean remaining planting potential of various provinces in China is available on Fig. 3.

2.2.3. Soybean-Cereal constraint model

The Soybean-Cereal Constraint Model consisted of the Farmland Constraint Line, the Total Output Function of Soybean and Cereal, Soybean-Cereal Production Constraint Line, Soybean-Cereal Earnings Constraint Line, and Soybean-Cereal Self-Sufficiency Rate Constraint Line. We assumed that agricultural technology progress would be limited in the short term, and climatic condition, consumption and import would be steady in the coming years.

We used the following formulas to calculate the different components of the model. The formula for Farmland Constraint Line is:

\[ x_{1} + x_{2} + x_{3} \leq X \]  

In the formula, \( x_{1} \) represents soybean planting area, while \( x_{2} \) represents cereal planting area and \( x_{3} \) represent other crops’ planting area. \( X \) is total farmland area.

The Total Output Function of Soybean and Cereal is calculated as:

\[ a_{i}x_{1} + \beta x_{2} = O_{i} \ (i = 1, 2, \ldots, n) \]  

In the formula, \( a \) and \( \beta \) are constants (i.e., output per unit area). \( O_{i} \) is the total output of soybean and cereal, and \( i \) represents four different scenarios used in this study. When \( x_{1} \) and \( x_{2} \) are most reasonable, \( O_{i} \) is optimum.

According to Farmland Constraint Line Eq. (2) and the relationship between crop area and yield, the Soybean-Cereal Production Constraint Line is calculated using the following formula:

\[ y_{1} + y_{2} = Y \]  

In the formula, \( y_{1} \) and \( y_{2} \) are constants, \( y_{1} \) represents soybean production (\( y_{1} = ax_{1} \)), while \( y_{2} \) represents cereal production (\( y_{2} = \beta x_{2} \)). This formula is used to reflect the restrictive relationship between soybean and cereal output, and the impact of increase of one unit of soybean output on cereal output.

Similarly, the Soybean-Cereal Earnings Constraint Line is calculated using the formula:

\[ \mu_{1}y_{1} + \mu_{2}y_{2} = E \]  

In the formula, \( \mu_{1} \) and \( \mu_{2} \) are constants, \( \mu_{1} \) represent total soybean earnings (i.e., soybean planting area multiplied by earnings per unit area), while \( \mu_{2} \) represent total cereal earnings. It is used to reflect the restrictive relationship between the total earnings of soybeans and cereals in China. In other words, it quantifies changes in earning from planting cereals to planting soybeans.

Finally, the Soybean-Cereal Self-Sufficiency Rate Constraint Line is calculated using the formula:

\[ \sigma_{1}r_{1} + \sigma_{2}r_{2} = R \]  

In the formula, \( \sigma_{1} \), \( \sigma_{2} \) and \( R \) are constants, \( r_{1} \) represents soybean self-sufficiency rate (i.e., domestic production divided by consumption), while \( r_{2} \) represents cereal self-sufficiency rate. It is used to reflect the restrictive relationship between the self-sufficiency rate of soybean and cereal in China (i.e., trade-offs between the self-sufficiency of soybean and cereal. Eq. (4)–(6) are derived from the deformation of Eq. (2).

2.2.4. Scenario analysis

Scenario analysis is a method used to describe the uncertainty of future development in a variety of options (Lou, 2012). Faced with uncertainties in soybean import, we applied different scenarios to understand the potential and challenges for growing soybean in China. Scenario A: China cannot import soybeans due to the COVID-19 outbreak. Scenario B: China can import one-quarter of the original amount. Scenario C: China can import half of its original amount. Scenario D: China cannot import food including soybean. These four scenarios were analyzed using the Soybean-Cereal Constraint Model to explore soybean potential productivity and to depict the relationship between soybean and food security in China. The schematic diagram of this model is available in the graphical abstract.

3. Results

3.1. Potential productivity of soybeans in China

The Soybean Suitability Distribution Model suggested that the areas suitable for soybean cultivation in China were 164.3 million ha, mainly distributed in the northeastern, central, eastern and southern regions (Fig. 3). These regions are categorized as the second and third grades of the terrain ladder, and under the influence of monsoon climate. Based on the average yield per unit area of soybeans during the past 19 years (1763.7 kg/ha), the calculated potential soybean production was 289.8 million tons.

During the past 19 years, soybean planting area showed a downward trend in China, with Jilin Province, Liaoning Province and North China showing the largest decline. Some exceptions were observed in Heilongjiang Province, Inner Mongolia Autonomous Region and Southwest China where we found some increases (Fig. 4). Currently, Heilongjiang Province, Anhui Province and Inner Mongolia Autonomous Region are the provinces with the most soybean cultivation. Heilongjiang Province accounted for 38.7% of total soybean production in the country. However, China can further look on the potential of planting soybean in Inner Mongolia Autonomous Region and Sichuan Province, and diversify
the planting area to reduce the risks that may arise from concentrated planting.

3.2. Scenario analysis

The soybean consumption was 103.9 million tons (average of recent 3 years), and its area was 8.9 million ha (Fig. 3, average of recent 19 years). The cereal production was 614.7 million tons, and the consumption was 635.9 million tons (average of recent 3 years), and its planting area was 89.1 million ha, while other crops was 61.3 million ha (average of recent 19 years). The total farmland area in mainland China was 177.9 million ha (Fig. 3), including fallow land and uncultivated land. The average net earnings of 1 hectare of soybean was 674.4 RMB, while cereals was 1,493.1 RMB in the past 19 years. Based on the above data, our Soybean-Cereal Constraint Model suggested the following relationship between soybean production and food security.

3.2.1. Scenario A—China cannot import soybeans

Domestic soybean production needs to be increased by 88.9 million tons in an extreme situation during which soybean trade chain is blocked due to COVID-19 pandemic and China cannot import soybeans to balance its supply and demand. Consequently, the domestic planting area must be increased to 58.2 million ha (Fig. 5), which is 6.9 times that of the current soybean planting area or equivalent to 33% of the total farmland area.

Based on the analysis results of soybean total potential productivity, this scenario is theoretically achievable because China has enough arable land suitable for soybean cultivation. However, the large-scale increase of soybeans may inevitably affect the cultivation of other food crops, so it is necessary to discuss the impact of soybeans on food security in this scenario. If China does not import any soybean, the cereal planting area will decline by 30.7 million ha, and cereal production will decline by 211.6 million tons (Fig. 5). Because cereal self-sufficiency rate will drop to 63.4%, not importing soybeans will affect food security.

3.2.2. Scenario B—China can import one-quarter of the original amount

In this scenario, China needs to produce 81.7 million tons of soybean and requires an additional 30.7 million ha of soybean planting area (Fig. 5). Considering the impact on cereal, cereal planting area will be reduced by 18.2 million ha (20.4% of the total cereal planting area). Considering this situation, China needs to increase soybean cultivation area to 38.5 million ha (21.6% of the total farmland area) and block soybean trade chain due to COVID-19 pandemic. It includes the area of farmland, the area suitable for planting soybeans and the actual average soybean planting area in China, and their production is calculated according to the output per unit area.
area). Consequently, the self-sufficiency rate of cereal will be reduced to 76.9%.

3.2.3. Scenario C—China can import half of the original amount

In this scenario, China needs to produce 59.4 million tons of soybean to balance its supply and demand. China will need an additional 18.3 million ha of soybean planting area (Fig. 5) and this will reduce the self-sufficiency rate of cereal to 90.4%. Although Chen and Zhou (2005) suggested that food security will not be affected if cereal sufficiency rate is >90%, China may still need to consider this scenario carefully as COVID-19 pandemic potentially disturbs the supply chain of other commodities.

3.2.4. Scenario D—China cannot import food including soybean

If the embargo and control measures taken by countries due to the outbreak affect the world’s food supply chain, China can only use the remaining cultivated land for soybean planting to increase the soybean planting area to 24.4 million ha. Therefore, in this scenario, soybean planting area can increase 1.9 times, resulting in a potential soybean production of 43.6 million tons and soybean self-sufficiency rate of 42% (Fig. 5).

3.3. Trade-off analysis of soybean production and food security in China

According to the results of the scenario analysis, it is difficult for China to simultaneously meet the large demand for soybean and cereal due to limited planting area. China can grow up to 804.1 million tons of cereals or 208.2 million tons of soybeans when the average production of other cash crops remains unchanged. As each additional unit of soybean production resulted in a 3.9 unit decrease in cereal production (Fig. 6a), producing soybean have no comparative advantage over cereal (Yin and Chen, 2019). In addition, soybean produces a lower net earnings than cereal. Even if the increased supply of soybean does not affect the prices of soybean and cereal, the current earnings from cereal will fall by 2.1 units for every unit of earning from soybean (Fig. 6b). Therefore, soybean also have no comparative advantage over cereal in terms of income generation. The Soybean-Cereal Self-Sufficiency Rate Constraint Line suggested that for every 1% increase in

Fig. 4. The variation and potential of soybean planting area in China. Soybean remaining planting potential is calculated by Eq. (1).
soybean self-sufficiency rate, the cereal self-sufficiency rate would fall by 0.6% (Fig. 6c). When the cereal is completely self-sufficient, the upper limit of soybean self-sufficiency is 42%. Thus, from the perspective of production or economic benefit, there is a big gap between soybean and cereal in China.

Although 92% of the cultivated land in China is suitable for soybean cultivation, there will be a trade-off between soybean and total food production. To optimize the trade-off, there are some potential avenues that can be adopted based on the Soybean-Cereal Constraint Model.

1) Increasing the value of X to X’ (increasing farmland area). This will shift the farmland constraint line outward, thereby increasing the potential productivity of soybeans (Fig. 7a).
2) Increasing the yield per unit area for both soybeans and cereals. Soybean yield in China is low, with \( a/β \) (ratio of output per unit area of soybean to cereal) of only 0.26. Therefore, the development of soybean cultivation technology, large-scale cultivation and denser planting (increase \( a \), the output per unit area of soybean) will increase soybean production \( (y_1) \) (Fig. 7b) without affecting the cereal planting area \( (x_2) \). Higher cereal yields per unit area \( (β) \) also means that more farmlands are available for growing soybeans (Fig. 7c).
3) Reducing the cultivation of other crops \( (x_3) \) so that more farmlands are available \( (x_1+x_2) \) to increase soybean and cereal production (Fig. 7d).

4. Discussion

This study using Soybean Suitability Distribution Model to explore the potential productivity of soybean in China as soybean imports are hampered by the COVID-19 outbreak. Based on the scenario analysis, food security in China will be compromised by increasing soybean cultivation. If China does not import soybeans at all, cereal production will be reduced by 34.4% and the cereal self-sufficiency rate will drop to 63.4% (Fig. 5). Even if only 50% of the original import volume is imported, the risk of food insecurity remain as cereal self-sufficiency rate drops to 90.4%. The self-sufficiency of cereal is still a prerequisite for soybean cultivation.

Since the \( β \) coefficient is larger than \( a \) in the Soybean-Cereal Constraint Model, under the constraints of land availability, planting more soybeans will reduce the total output (Fig. 7a). For example, the total output of scenario A is 172.5 million tons less than that of scenario D. The largest \( O \) will appear at the intersection of the scenario line and the farmland constraint line \((0,116.6)\), or when no soybeans are planted. Therefore, soybean is a “Gordian Knot” in China’s food security. However, China has a huge demand for soybean. Once the food supply chain is interrupted or blocked, soybean imports may decrease and soybean prices will rise significantly. Consequently, the price of soybean products such as soybean oil and the cost of downstream industries such as breeding industry will rise, potentially increasing the price of cereal and
other food products. In the long run, it will ultimately have an impact on the quality of life as food security declines. Therefore, preventing the reduction of cultivated land (Wang et al., 2019), converting non-grain production to soybean production on cultivated land (Su et al., 2020) and improving the productivity of cultivated land are important to solve soybean import dependency (Fig. 7a). Because planting soybean is also costly and offers low economic return (earning is only 45.2% of cereal and 2.2% of apples per unit area, and even negative during the past five years) (Niu et al., 2007; Cavalett and Ortega, 2009; Cheng, 2013), the art of making soybean cultivation a profitable business becomes the focus of developing soybean potential. The Chinese government can also consider occupying the areas for other cash crops other than cereal to increase soybean planting area when necessary (Fig. 7d).

Agricultural land suitability analysis is one of the key tools for ensuring sustainable agriculture and for attaining the current Sustainability Development Goals of United Nations (Akpoti et al., 2019). Based on a study by He (2011) concluded that the area suitable for planting spring soybean is 700 million ha, while that for summer soybean is 681 million ha. However, its model index does not include land-use types, but the existing urban land, water and forest land are not suitable for soybean cultivation. Therefore, in this paper, we tried to improve the projection by using farmlands to calculate soybean suitability distribution. Another study by Zhang et al. (2014) calculated the spatial distribution of soybean production potential using the GAEZ model. The result suggested that the potential area for soybean production is 165 million ha, which is similar to the 164.3 million ha calculated in this study. Wu et al. (2020) through Emerge Sustainability Indices suggested that Yunnan is the most appropriate place for planting soybean. This result can be used as the realization area of soybean macro-control management. Although our article does not analyze the sustainability of cultivating soybean from an ecological perspective, Southwest China is also another important area from the perspective of soybean planting potential. In addition, several studies have shown that replacing maize with soybean in some regions will contribute to the sustainability of the entire food supply system in China without significant domestic environmental costs (Wang et al., 2018; He et al., 2019). Because China has low soybean self-sufficiency rate, the unsustainable and scarce soybean supply likely fails to meet such a huge demand (Wu et al., 2020). But with decreasing cereal self-sufficiency rate by 0.6% for every 1% increase in soybean self-sufficiency rate (Fig. 6c), a robust and efficient management of agricultural lands is required for sustainable agricultural development and food production (Montgomery et al., 2016).
The Second Sustainable Development Goal (SDG2) presents the ambitious target of ending hunger globally by 2030 (United Nations, 2015). However, climate change has impeded and will continue to impede progress on reducing hunger (D’Croz, 2019). The global COVID-19 outbreak further generates uncertainties in the international food market and food supply, potentially adding the number of people who are at risk of suffering acute hunger. With a population of 1.4 billion, food security is always a top priority for China. It is predicted that grain demand would increase to 650 million tons in 2030 (Xiang and Zhong, 2013). A sustainable soybean supply chain is therefore vital for China. But because soybean cultivation takes time, in the short term, it is necessary to formulate a strategy to strengthen international cooperation rather than cultivate soybean. In addition, it is necessary to increase soybean and food reserves, and improve the current food reserve regulations and food emergency protection mechanisms. In the long run, increasing soybean planting area in areas with high soybean planting potential such as Inner Mongolia Autonomous Region, Sichuan Province, and Yunnan Province are fundamental to provide a sustainable supply of soybean.

The quantity of the grain supply in China is abundant at present, but the disequilibrium in grain type sufficiency requires China to increase its soybean production (Wang et al., 2018). We tried to address the problem by focusing on the trade-off analysis between soybean and cereal. However, this study is also limited in several ways. For example, we did not weigh soybean against other crops. The income from planting other cash crops such as apple is much higher than that of soybean. Farmers are more inclined to plant profitable crops. Therefore, the crop suitability distribution model and the constraint model can be applied to analyze the management of cultivated land such as the analysis of other cash crops and cereal, or the analysis of soybean and other cash crops for future uses. However, it should be noted that the Suitability Distribution Model and scenario analysis in this study mainly used limit methods, required some static assumptions and considered only the extreme conditions, which may or may not happen in reality. Farmland is used as the land-use type suitable for soybean planting, but it can be divided into irrigated and non-irrigated lands. In this study, the irrigated and non-irrigated land were not analyzed separately. Thus, this study is limited because the impacts of different water and temperature conditions on soybean yield were not considered. There are also different thresholds of temperature requirements for soybean growth which needs further study. There are also other factors such as farmers’ willingness to plant soybean that needs to be considered. This article also does not analyze how China can secure its food supply chain or how China can leverage its food control system as both require more extensive research. However, we provided: 1) a theoretical reference for balancing the development of soybean potential and food supply in the context of national food security strategy, as well as 2) ideas for sustainable agricultural management and sustainable supply chain adjustment.

5. Conclusions

This paper studied the soybean potential productivity in China based on the Suitability Distribution Model and Soybean-Cereal Constraint Model. Using the four scenarios to explore some possible relationships between soybean production potential and food security, we found that:

1) With an average soybean consumption of 103.9 million tons during the past three years but low self-sufficiency rate (15%), soybean planting area will need to be increased by 6.9 times if outbreaks such as COVID-19 prevent China from importing soybean. However, the cereal self-sufficiency rate will then drop to 63.4%. Without affecting the cultivation of cereals, the self-sufficiency rate of soybeans is limited to 42%. Consequently, China will still need to import more than 68% of its current import volume of soybean.

2) The soybean total potential productivity in China is very high. Based on this study, the potential total planting area is 164.3 million ha and the potential production is 289.8 million tons. But it should be
noted that each additional unit of soybean production in China will result in a 3.9 unit decrease in cereal production. For every unit of earning from soybean cultivation that replaces cereal cultivation, the original cereal earnings will fall by 2.1 units. For every 1% increase in soybean self-sufficiency rate, the cereal self-sufficiency rate will fall by 0.6%.

3) China will not experience food security problems in the short term. But as soybean imports decrease, soybean demand will be forced to cut. In the long term, increasing soybean self-sufficiency rate and developing the area with high soybean remaining planting potential such as Inner Mongolia Autonomous Region, Sichuan Province, Yunnan Province and other areas are crucial to ensure a sustainable supply of soybean.

**Declaration of Competing Interest**

The authors declare that they have no competing interests. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

**CRediT authorship contribution statement**

**Huizong Yao:** Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Methodology. **Xiaozing Zuo:** Methodology, Software, Formal analysis, Investigation, Data curation, Writing - original draft. **Daxing Zuo:** Methodology, Software, Validation, Formal analysis, Data curation, Writing - original draft. **Han Lin:** Methodology, Software, Formal analysis, Data curation, Writing - original draft. **Ximeng Huang:** Validation, Formal analysis, Writing - original draft. **Chuanfu Zang:** Project administration, Supervision, Visualization, Writing - review & editing, Writing - original draft, Data curation, Resources, Investigation, Formal analysis, Software, Methodology, Conceptualization.

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