

Soybean Rust and Resistant Cultivar Effects on Global Soybean Supply and Demand

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Abstract

Soybean rust (SBR) is a damaging disease that has threatened soybean production worldwide. In Brazil, the world's top soybean exporting country, SBR-resistant cultivars have been developed to prevent severe soybean production losses. To evaluate SBR effects on soybean production in Brazil and on the global soybean market, we developed soybean supply and demand models for Brazil, the U.S., Argentina, China, the EU-28, and the rest of the world based on functions that include yield, area, exports, imports, stock changes, demands, and price linkages. Three scenarios were set: no production loss caused by SBR, severe production loss caused by ineffective fungicides, and the adoption of SBR-resistant cultivars. To evaluate the effects of SBR and SBR-resistant cultivars on soybean production and the global soybean market, our simulation results suggest that the world price of soybeans would increase due to severely damaged soybean production. The adoption of resistant cultivars can alleviate losses in soybean production and reduce costs for fungicide application. Therefore, adopting SBR-resistant cultivars in soybean production is necessary to maintain a stable global supply of soybeans.

Discipline: Social Science

Additional key words: adoption of resistant cultivars, fungicide application, production loss, saving costs

Introduction

Soybean rust (SBR) caused by *Phakopsora pachyrhizi* has strongly affected soybean production, with reported yield losses of more than 80% of yield (Yorinori et al. 2005). The disease was first detected during the 2000/2001 crop season in Brazil. Effects worsened rapidly because the disease was novel and fungicide application remained ineffective, thereby resulting in an 8.49% loss of soybean production during the 2003/2004 crop season (Godoy et al. 2016). Economic losses sustained by soybean production due to the occurrence of SBR were estimated as about USD1.22 billion. The fungicide cost was USD2.08 billion. In 2004, the Anti-Rust Consortium was established to control SBR. Several strategies have been recommended to manage SBR in Brazil, such as the implementation of soybean-free periods, application of fungicides, and cultivation of SBR-resistant cultivars (Consórcio Antiferrugem 2019). Among these strategies, the main production regions in Brazil adopted a soybean-free

period and fungicide application, eventually leading to a reduction of losses in soybean production (Godoy et al. 2016). However, fungicide application has gradually become ineffective year by year due to the appearance of fungicide-resistant races of SBR (Godoy et al. 2016). Consequently, soybean cultivars resistant to SBR have been developed. As of 2017, five SBR-resistant cultivars have been registered with Brazil's Ministry of Agriculture, Livestock and Food Supply (MAPA). However, these resistant cultivars represent only 0.44% of all registered soybean cultivars grown throughout the country, and are not yet popular or commonly adopted by farmers for cultivation (Childs et al. 2018).

In 2018, Brazil produced 122 million metric tons (MT) of soybeans, exporting 78.5 million MT. Brazil ranked second among the top soybean producing countries and first among the top soybean exporting countries (USDA PS&D). The three major soybean producing countries (Brazil, the U.S., and Argentina) export 88.6% of the world's soybean supply. Soybeans are used mainly as processed products worldwide.

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After soybean oil is extracted, the remainder is used as livestock feed. Soybean oil is consumed as food and used for biodiesel production. As a consequence of global warming, there is growing demand for renewable energy resources such as biodiesel. The demand for soybean oil and livestock feed is also increasing, especially in China and the EU-28, with respective shares of 57.5% and 10.4%, as of 2018 (USDA PS&D). Recently, a shift has occurred in the balance among exporting and importing countries. Brazilian exports have surpassed those of the U.S., and soybean exports from Brazil to China are increasing due to China’s demand for oil and feed (FAPRI 2018).

Any soybean production loss in Brazil because of SBR would reduce exports and likely affect the global soybean market. Soybean production on the global soybean market has been studied econometrically. The projected productions of the main soybean producing countries obtained from those studies were used until 2007 for determining production (Huyser 1983, Koizumi & Ohga 2008, Masuda & Goldsmith 2009, Meyers et al. 1986, 1991). However, no subsequent projection of soybean production reflects the most recent trends and changes in the global market. Recent shifts in the global soybean trade must be incorporated into the analyses. Moreover, the effect of SBR was not considered in these studies because SBR has only recently emerged in Brazil. Therefore, we investigated the effects of SBR and SBR-resistant cultivars on soybean production and the global soybean market. For this purpose, we developed a global supply and demand model for soybeans in Brazil, the U.S., Argentina, China, the EU-28, and the rest of the world with three scenarios: (1) a scenario where SBR did not cause damage to soybean production, (2) a scenario where fungicide becomes ineffective, causing extensive loss in soybean production, and (3) a scenario where SBR-resistant cultivars of soybeans were adopted for cultivation.

Model

1. Overview of the global supply and demand model

We developed a global model of soybean supply and demand. To evaluate the effects of SBR and SBR-resistant cultivars on soybean production and the global soybean market, we used the global supply and demand model for soybeans based on the models of Koizumi & Ohga (2008) and Hung et al. (2018), with some modifications. Our model consists of 50 functions and 13 identities. We estimated soybean production from the functions for yield and area harvested.

The yield (*Y*) function in each country

(six functions) is

$$Y_{i,t} = \alpha_{yi} + \beta_{yi} T, \tag{1}$$

where α_i and β_i are the parameters estimated as statistically significant. Subscripts *i* and *t* denote the country applied and time index, respectively, and *T* represents the time trend.

The area harvested (*A*) function in each country (six functions) is

$$A_{i,t} = \alpha_{ai} + \beta_{ai} A_{i,t-1} + \beta_{a2i} RFP_{i,t-1}, \tag{2}$$

where *RFP* stands for the real farm price deflated by the consumer price index (*CPI*).

Production in each country (*QPR*, six identities) is expressed as

$$QPR_t = \sum_i Y_{i,t} A_{i,t}, \tag{3}$$

The export (*EXP*) functions for exporting countries (three functions) are

$$EXP_t = \alpha_{exi} + \beta_{exli} QPR_{i,t} + \beta_{ex2i} soyRWP_{i,t}, \tag{4}$$

where *soyRWP* signifies the real world price of soybeans (*soyWP*) deflated by the *CPI*. Here, *soyWP* is represented by the US No. 2 yellow meal, CIF Rotterdam.

The import (*IMP*) functions for importing countries and regions (three functions) are

$$IMP_t = \alpha_{imi} + \beta_{im1i} QPR_{i,t} + \beta_{im2i} soyRWP_{i,t}, \tag{5}$$

The stock change (*STC*) functions (six functions) are

$$STC_{i,t} = \alpha_{si} + \beta_{s1t} (QPR_t - QPR_{t-1}) + \beta_{s2i} (RFP_{i,t} - RFP_{t-1,i}), \tag{6}$$

The market clearing identity (six identities) is

$$QPR_{i,t} + IMP_{i,t} = EXP_{i,t} + STC_{i,t} + PROC_{i,t} + FE_{i,t} + FO_{i,t} + SE_{i,t} + LO_{i,t}, \tag{7}$$

where *PROC*, *FE*, *FO*, *SE*, and *LO* represent the quantities of soybeans for processing, feed for livestock, food, seed, and loss, respectively.

The demand function of soybeans for processing (six functions) is

$$PROC_{i,t} = \alpha_{pi} + \beta_{p1t} SBoilRWP_{i,t} + \beta_{p2t} SBcakRWP_{i,t} + \beta_{p3t} GDPPC_{i,t}, \tag{8}$$

where $SBoilRWP$ and $SBcakRWP$ are the real world prices of soybean oil ($SBoilWP$) and cake ($SBcakWP$) deflated by the CPI , respectively, and $GDPPC$ is the per-capita real gross domestic product (GDP) divided by population (POP). Here, $SBoilWP$ and $SBcakWP$ denote Dutch crude degummed, FOB NW Europe and Brazilian pellets 48% protein, CIF Rotterdam, respectively.

The demand function of soybeans for feed (four functions) is

$$FE_{i,t} = \alpha_{fei} + \beta_{fe1i} RFP_{i,t} + \beta_{fe2i} pigPRD_{i,t} + \beta_{fe3i} chPRD_{i,t} \quad (9)$$

where $pigPRD$ and $chPRD$ signify pig and chicken production (MT), respectively. Brazil and Argentina do not consume soybeans directly for feed, but consume processed soybean cake for feed. Therefore, the demand functions of soybeans for feed in those two countries were not applied.

The demand function of soybeans for food per capita (two functions) is

$$FDPC_{i,t} = \alpha_{foi} + \beta_{fo1i} RFP_{i,t} + \beta_{fo2i} GDPPC_{i,t} \quad (10)$$

The expression can be recast as shown below.

$$FDPC_{i,t} = \frac{FO_{i,t}}{POP_{i,t}} \quad (11)$$

Because Brazil, the U.S., Argentina, and the EU-28 do not consume soybeans directly for food, but consume processed soybean oil as food, the demand functions of soybeans for food in these countries were not applied.

The global market equilibrium is explained below. Gross exports and imports for each country were applied to obtain the equilibrium price through application of the Gauss–Seidel algorithm as (1 identity) as follows:

$$\Sigma EXP_{i,t} = \Sigma IMP_{i,t} \quad (12)$$

The price linkage functions (14 functions) are

$$SBoilWP_{i,t} = \alpha_{oi} + \beta_{oi} FP_{i,t} \quad (13)$$

$$SBcakWP_{i,t} = \alpha_{ci} + \beta_{ci} FP_{i,t} \quad (14)$$

$$FP_{i,t} = \alpha_{sbi} + \beta_{sbi} soyWP_{i,t} \quad (15)$$

Figure 1 presents a flowchart of the global supply and demand model of soybeans. Domestic utilization of soybeans is defined as the sum of feed, food, seed, and loss. The supply of soybeans is influenced by production, domestic utility, exports, imports, stock changes, domestic farm prices, and the world price of soybeans. Soybean demand is influenced by processing, livestock production, domestic farm prices, world prices of soybean oil and cake, population, gross domestic production, and

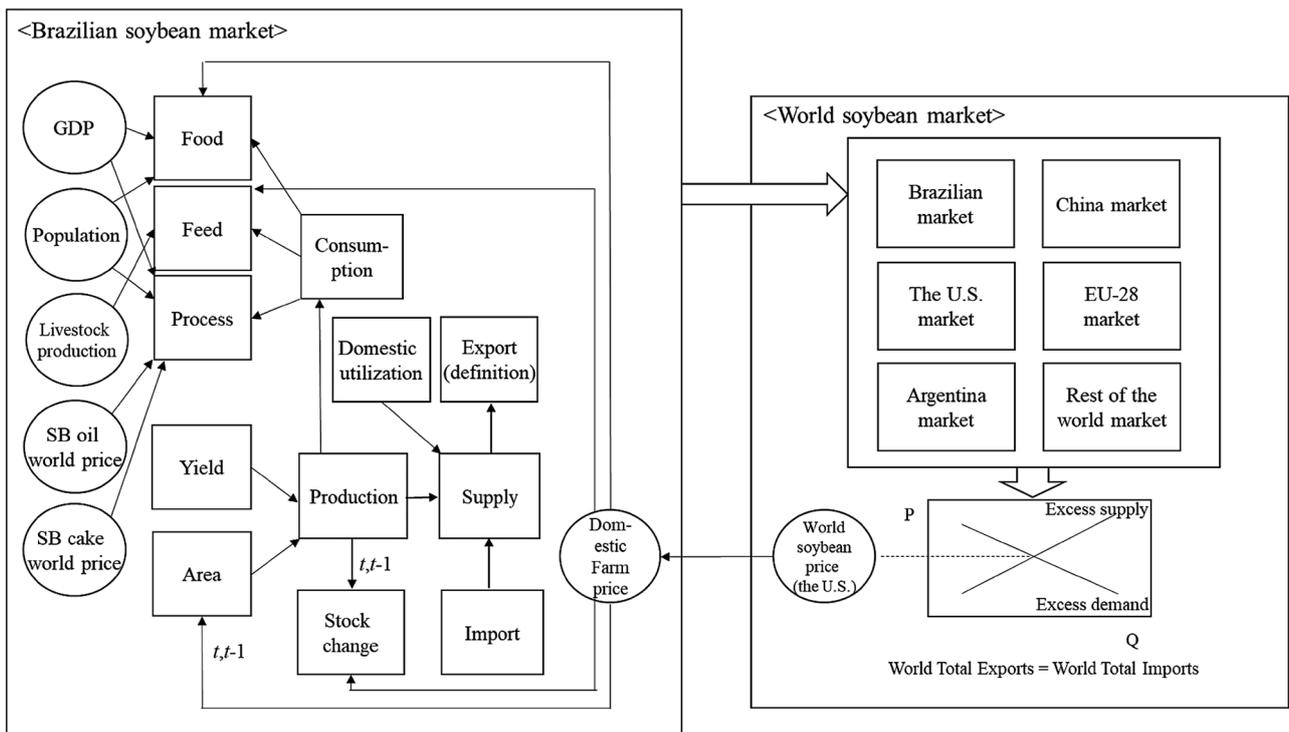


Fig. 1. Flowchart of the world soybean supply and demand model

the consumer price index. Domestic farm prices, which are linked to the world prices of soybean oil and cake, affect the supply of the following year. World prices of soybeans are determined when the world sum of exports and imports are in equilibrium. The exchange rate, world prices of soybean oil and cake, exports from Brazil, the U.S., and Argentina, imports in China, the EU-28, and rest of the world, population, and gross domestic products are exogenous variables.

2. Data

The estimated period was 1992-2013, when all data were available. Data except for those of the U.S. for *Y*, *A*, *FP*, *EXP*, *IMP*, *STC*, *PROC*, *FE*, *FO*, *SE*, and *LO* were obtained from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). These data in the U.S. were obtained from Production, Supply and Distribution of the U.S. Department of Agriculture (USDA PS&D). Data for the U.S. of *CPI*, *GDP*, *POP*, *GDPD*, and *EXR* were obtained from FAOSTAT. Data of *soyWP*, *SBoilWP*, and *SbcakWP* were obtained from the World Bank. Data for the U.S., China, the EU-28, and the rest of the world of *pigPRD* and *chPRD* were obtained from the USDA PS&D. Data of the *CPI* in Brazil and Argentina were unreliable because of hyperinflation. For that reason, we used data for the U.S. The forecast period was 2019-2030. With data of the USDA PS&D obtained during 2014-2018, we calibrated the respective functions of *Y*, *A*, *EXP*, *IMP*, *STC*, and *PROC*.

Analysis

1. Assumptions

We assumed that the growth rate in population during 2011-2013 in Brazil, that during 2015-2017 in the U.S., Argentina, the EU-28, and the rest of the world, and that during 2016-2017 in China will last throughout the forecast period. We assumed that the growth rate in the *CPI* during 2011-2013 in Brazil, during 2014-2016 in the U.S., during 2015-2017 in Argentina and the EU-28, during 2016-2017 in China, and 2010-2012 in the rest of the world will last throughout the forecast period. We also assumed that the real *GDP* during 2015-2017 in Brazil, and during 2014-2016 in all countries other than Brazil will last throughout the forecast period.

2. Simulation analysis

To evaluate the effects of SBR and SBR-resistant cultivars on soybean production, we set up three scenarios. The base scenario entails maintenance of the current situation. Scenario 1 is the case where soybean production is not affected by SBR. Scenario 2 is the case

where fungicides are ineffective and soybean production is gradually damaged due to SBR. Scenario 3 represents the case where SBR-resistant cultivars are adopted. In each scenario, we estimated the equilibrium world price of soybeans.

In scenario 1, we measured the yield function by recovery of damage caused by SBR based on earlier reported grain losses (Godoy et al. 2016). In scenario 2, we described that fungicide effects on soybean production fade gradually as fungicide-resistant SBR races emerge (Godoy et al. 2016). Some fungicides are used in Brazil (Consórcio Antiferrugem 2019). Among these fungicides, dimethylation inhibitors (DMIs) were initially most useful, but the efficacy of DMIs is decreasing (Consórcio Antiferrugem 2019). We applied the logarithmic function to show the efficacy of DMIs (E_{DMI}) as presented below because efficacy reduction showed not a straight line but curvilinear one instead as

$$E_{DMI}(t) = a_e + \frac{b_e - a_e}{1 + EXP[-c_e(t - d_e)]} + e_e t, \tag{16}$$

where a_e and b_e represent the minimum and maximum efficacy, respectively, c_e denotes the efficacy decrease rate, d_e signifies the inflection year, and e_e stands for the slope of the time trend. The greatest loss was incurred during the 2003/2004 crop season in Brazil, when 8.49% of soybean production was lost (Godoy et al. 2016). The minimum efficacy in Eq. (16) reflected the largest loss rate in this year. In scenario 3, we described the situation where the herbicide Intacta and pest-resistant cultivars were introduced and adopted in Brazil. The gene-modified soybean accounted for approximately 94% of cultivars in 2016 (ISAAA 2017). As of 2017, approximately 89% of all cultivars registered and protected in MAPA were Intacta cultivars (MAPA). The planted area of these cultivars was 7.9% in 2013. It expanded to 60.9% in 2016. Based on this diffusion rate, we estimated the harvested area of the SBR-resistant cultivars according to the modified equation of technology diffusion (Griliches 1957) as

$$A_c(t) = a_c + \frac{b_c - a_c}{1 + EXP[-c_c(t - d_c)]} + e_c t, \tag{17}$$

where a_c and b_c denote the minimum and maximum area harvested of the SBR-resistant cultivars, respectively. Also, c_c represents the diffusion rate, d_c stands for the inflection year, and e_c is the harvested area increase rate at baseline estimation. Based on the case of Intacta, we assumed that the SBR-resistant cultivars are gene-modified cultivars and that the diffusion rate in 2019 is less than 4% (Childs et al. 2018). The inflection year is assumed to be 2021. The harvested area of conventional

cultivars and the harvested area of the SBR-resistant cultivars were subtracted from the estimated harvested area of scenario 2. The yield of the SBR-resistant cultivars assumed 3.11 MT/ha as being equal to that of an SBR-resistant cultivar (TMG7067IPRO) that was already released (Dorneles et al. 2019). Conventional cultivars of scenario 3 were assumed to be the same as those of scenario 2, and the harvested area will decrease with the lowered efficacy of fungicides. The yield of conventional cultivars of scenario 3 was assumed as being equal to that of the baseline estimation. We determined soybean production by multiplying the harvested area and the yield in each cultivar, and then summing the results.

Results

1. Estimated world soybean market

Table 1 shows the estimation results of parameters. World soybean production is estimated as increasing by an average annual rate of 0.32% during 2019-2030. The total production is expected to be 347 million MT in 2030. In Brazil, an average annual increase in soybean production of 0.60% is estimated, with total production of 127 million MT in 2030 (Fig. 2). The harvested area is also expected to expand (USDA FAS 2018a) with an estimated annual rate of increase of 0.82%. However, our model shows that soybean production in the U.S. will not increase. As a result, Brazil is expected to surpass the U.S. and become the world's largest producer of soybeans from 2022.

Figures 3 and 4 show soybean exports from Brazil and the U.S., respectively. Soybean exports from Brazil are estimated to increase at an average of 0.49% annually with a total of 78.7 million MT in 2030. However, soybean exports from the U.S. will not increase to a total of 52.0 million MT in 2030. This outlook is based on the assumption of continued trade friction between the U.S. and China. Soybean imports in China are estimated to be 87.3 and 87.6 million MT in 2019 and 2030, respectively (Fig. 5). The world price of soybeans is estimated as USD353.7/MT on average throughout 2030 (Fig. 6). The domestic farm price of soybean in Brazil is linked to the world price. Therefore, the estimated average domestic price is USD267.4/MT during that period.

Processed soybeans are used as food, for biodiesel production for industry, and as feed for livestock animals. Processed soybeans in Brazil and the U.S. are estimated to increase annually at an average of 0.54% and 1.03%, respectively. In 2018, 64.3% of soybeans produced in Brazil were exported, compared with 39.1% in the U.S. (USDA PS&D). However, 46.0% of soybeans produced in the U.S. are used as processed products, compared

with 35.0% of soybeans produced in Brazil (USDA PS&D). Consequently, soybeans produced in the U.S. are used mainly for domestic purposes as compared with soybeans produced in Brazil. The demand for processed soybeans in China is the greatest in the world: 88.0 million MT in 2018 (USDA PS&D). The increase in demand will probably be interrupted due to the recent proliferation of African swine fever (USDA FAS 2019). Processed and imported soybeans in China are estimated as averaging 86.9 and 87.2 million MT, respectively, during 2019-2030. In the EU-28, there is strong public opposition against genetically modified soybeans. The Common Agricultural Policy (CAP) has been enacted (USDA FAS 2018b). Therefore, the production of non-genetically modified soybeans is increasing continuously. Soybean imports in the EU-28 will not increase as much. Consequently, the average of soybean imports in the EU-28 is estimated as 15.7 million MT during 2019-2030.

2. Effects of SBR and SBR-resistant cultivars on global soybean markets

In scenario 1, the average annual increase in soybean production is estimated to be 1.13% during 2019-2030 (Fig. 7). When soybean production increases at this rate, soybean exports are expected to increase to 0.91%. Consequently, the world price and domestic farm price of soybeans will decrease to 2.86% and 3.56%, respectively. In scenario 2, soybean exports will decrease from 74.3 million MT in 2019 to 72.9 million MT in 2030 with soybean production loss. Consequently, by 2030, the world price and domestic farm price of soybeans will increase to USD422.8/MT (Fig. 8) and USD331.8/MT, respectively. Considerable production loss could result in soaring world prices of soybeans and soybean products. Soybean-importing countries would also reduce their imports because of high prices. Consequently, it would be difficult to meet increasing demands for livestock feed, biodiesel production, and edible oil from soybeans. In Brazil, soybean production is pursued as an agribusiness. Large areas of soybeans are cultivated by most soybean farms in one crop season (Sano 2015). Many diseases such as SBR are linked to genetic uniformity. Cultivation of this type renders soybeans readily vulnerable to diseases (Altieri & Pengue 2006). With global warming, climate conditions might become favorable to SBR growth. The fungicides might then become ineffective, resulting in an SBR epidemic, as assumed in scenario 2. With the adoption of SBR-resistant cultivars in scenario 3, soybean production is estimated as recovering 3.32% (Fig. 7). Soybean exports will also increase by 2.75% in 2030 as compared with scenario 2. In scenario 3, the world price of soybeans is estimated as USD396.5/MT

Table 1. Estimated parameters with *t*-values

Dependent variable	Explanatory variable	Brazil	U.S.	Argentina	China	EU-28	Rest of the world
<i>Y</i>	<i>Time trend</i>	0.0391 ^{†1} (6.54)	0.0227 (4.12)	0.0459 ^{†1} (5.40)	0.00591 ^{†1} (1.78)	0.0282 ^{†1} (2.40)	0.374 ^{†1,2} (5.97)
<i>A</i>	<i>A_{t-1}</i>	0.773 (5.42)	0.786 (6.64)	0.771 (10.2)	0.621 (3.78)	0.382 (2.89)	0.432 (3.21)
	<i>RFP_{t-1}</i>	4,504 (1.22)	4,742 (1.22)	3,398 (1.55)	186 (1.08)	136 (1.52)	1,003 (1.07)
<i>EXP</i>	<i>QPR</i>	0.577 (-15.3)	0.584 (8.02)	0.257 (16.6)	–	–	–
	<i>soyRWP</i>	10,905 (3.05)	19,894 (1.15)	3,108 (1.06)	–	–	–
<i>IMP</i>	<i>QPR</i>	–	–	–	-0.744 (-1.54)	-1.21 (-1.08)	-0.181 (-1.69)
	<i>soyRWP</i>	–	–	–	-2,466 (-1.81)	-15,700 (-5.05)	-6,691 (-1.36)
<i>STC</i>	<i>dQPR^{†3}</i>	–	0.300 (2.18)	–	0.314 (1.81)	0.819 (1.26)	0.109 (1.42)
	<i>dRFP^{†4}</i>	-11,312 (-1.08)	-29,340 (-1.78)	-17,824 (-1.55)	-847 (-2.00)	–	-2,175 (-1.19)
<i>FDPC</i>	<i>RFP</i>	–	–	–	-0.000582 (-3.22)	–	-0.000143 (-2.58)
	<i>GDPPC</i>	–	–	–	-0.0164 (-1.49)	–	0.0580 (1.83)
<i>FE</i>	<i>RFP</i>	–	-15,759 (-7.66)	–	-914 (-2.19)	-3,194 (-8.62)	-2,975 (-4.76)
	<i>pigPRD</i>	–	–	–	–	0.678 (1.12)	0.220 (3.57)
	<i>chPRD</i>	–	0.000917 (1.56)	–	0.620 (9.97)	0.353 (3.53)	–
<i>PROC</i>	<i>SBoilRWP</i>	-4,239 (-1.82)	-7,611 (-2.22)	-22,790 (-3.15)	-705 (-1.93)	-6,502 (-3.78)	-4,814 (-1.65)
	<i>SBcakeRWP</i>	-28,252 (-5.74)	-20,619 (-2.01)	-91,745 (-5.49)	-1,758 (-1.38)	-10,235 (-3.09)	-18,945 (-2.37)
	<i>GDPPC</i>	5,583,633 (9.25)	-789,195 (-1.50)	4,927,036 (2.39)	1,722,767 (13.1)	-755,436 (-3.04)	4,200,801 (1.47)
<i>SBoilWP</i>	<i>FP</i>	2.29 (9.84)	2.27 (9.09)	3.20 (5.45)	0.262 (6.51)	2.59 (11.3)	2.51 (8.21)
<i>SBcakeWP</i>	<i>FP</i>	0.914 (22.6)	0.962 (12.3)	1.63 (15.4)	0.0659 (6.89)	0.974 (19.2)	1.03 (13.4)
<i>FP</i>	<i>soyWP</i>	0.933 (27.0)	0.897 (24.5)	–	–	–	–

Note: “–” denotes that it does not apply to the country or region.

^{†1} Time trend becomes flat after 2014.

^{†2} Log trend was applied instead of the linear trend as a time trend.

^{†3} $dQPR = QPR_t - QPR_{t-1}$.

^{†4} $dRFP = RFP_t - RFP_{t-1}$.

(Fig. 8), whereas the domestic farm price of soybeans is estimated as USD307.4/MT. The adoption of SBR-resistant cultivars has also reduced the number of fungicide applications (Dorneles et al. 2019). In terms of the cost for fungicide application, SBR-resistant cultivars

could reduce production costs by USD1.14 billion each year (Table 1). The fungicide application cost in 2013/2014 crop year was 2.2 billion USD (Godoy et al. 2016), and adopting SBR-resistant cultivars could correspond to saving almost half of the SBR control cost. Therefore,

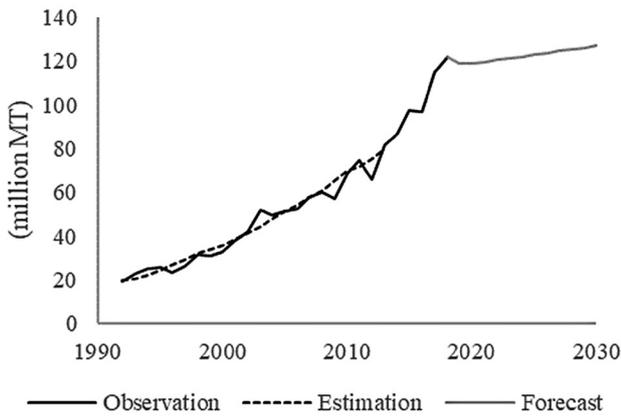


Fig. 2. Soybean production in Brazil

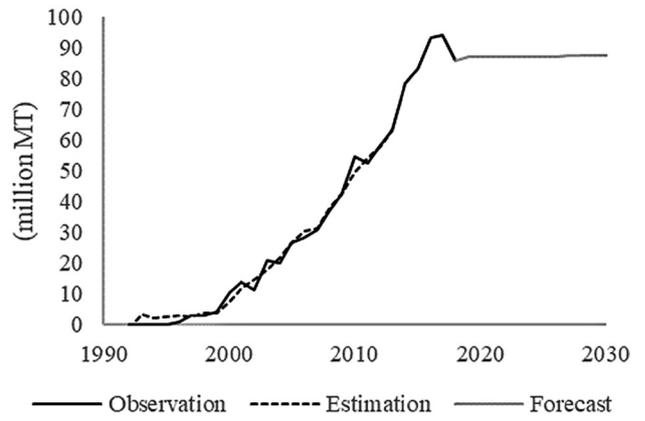


Fig. 5. Soybean imports in China

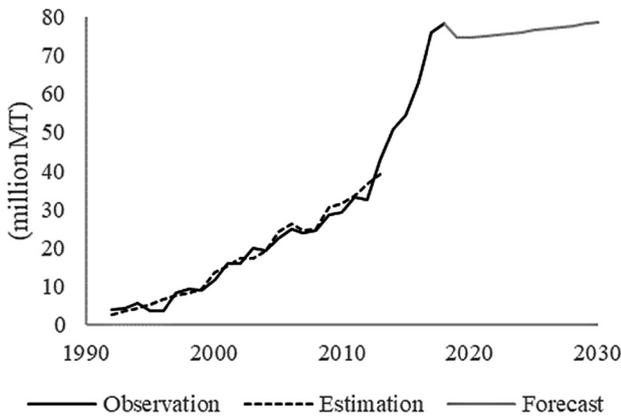


Fig. 3. Soybean exports from Brazil

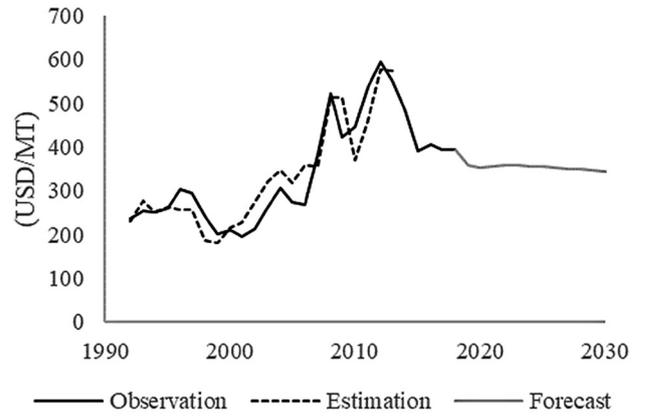


Fig. 6. World price of soybeans

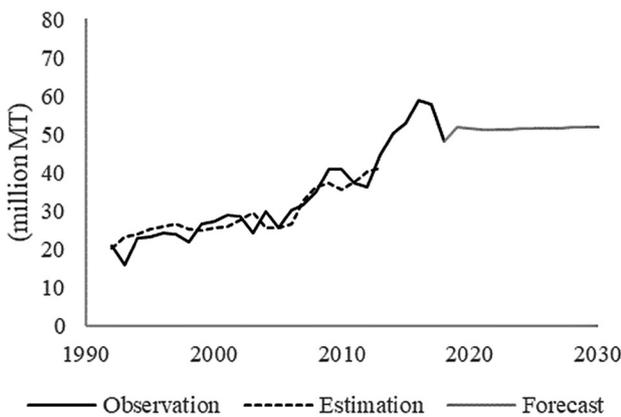


Fig. 4. Soybean exports from the U.S.

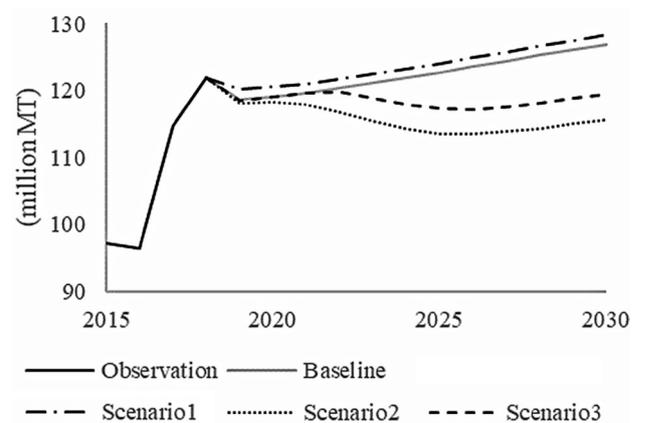
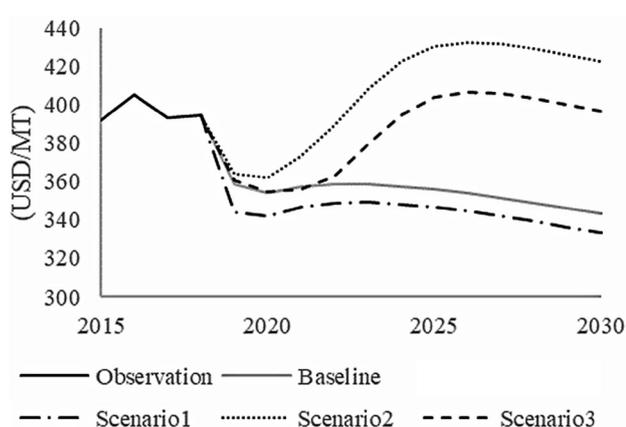


Fig. 7. Forecasts of Brazilian soybean production under the three scenarios

Table 2. Parameters for estimating cost savings when using SBR-resistant cultivars

Area harvested	39.2	million ha
Area harvested for SBR-resistant cultivars (a)	23.9	million ha
Area harvested for conventional cultivars (b)	15.2	million ha
Cost of fungicide application in (a)*	1.20	USD billion
Cost of fungicide application in (b)*	1.52	USD billion
Total cost of fungicide application in scenario 3	2.71	USD billion
Total cost of fungicide application in scenario 2	3.85	USD billion
Cost saving (scenario 3 – scenario 2)	1.14	USD billion

Fungicide is applied twice for resistant cultivars and four times for conventional cultivars (Dorneles et al. 2019). Fungicide cost is assumed to be USD25/ha/spray (Godoy et al. 2016).

**Fig. 8. Forecasts of world soybean prices under the three scenarios**

adopting SBR-resistant cultivars might contribute to increased incomes for farmers. A large-scale and immediate adoption of SBR-resistant cultivars is recommended for sustainable soybean production recovery that would eventually benefit local farmers. For the dissemination of SBR-resistant cultivars, the cooperation of local farmers in integrating soybean-free period cultivation and appropriate fungicide usage are also indispensable for the effective control of an SBR outbreak.

Conclusions

Soybean production in Brazil is facing a severe threat because of SBR, which could lead to severe repercussions in the supply and demand of soybeans in the global market. If the current situation continues, then our model estimated for 2030 Brazil will produce 127 million MT of soybeans and export 78.7 million MT of soybeans. If fungicides become ineffective and soybean production decreases, then production and soybean exports are estimated as 116 and 72.9 million MT, respectively. A marked reduction of soybean production

in Brazil would reduce soybean quantities in the world market and likely lead to increased world prices of soybeans and probable confusion in the global soybean market. Adopting SBR-resistant cultivars would not only support the recovery of soybean production in Brazil but would also reduce the costs of using fungicides to about half and lead to the recovery of soybean production in Brazil, in addition to maintaining a stable global soybean supply.

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