International Food and Agribusiness Management Review
Volume 12, Issue 4, 2009

World Soybean Production: Area Harvested, Yield, and Long-Term Projections

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Abstract

Soybeans (*Glycine max*) serve as one of the most valuable crops in the world, not only as an oil seed crop and feed for livestock and aquaculture, but also as a good source of protein for the human diet and as a biofuel feedstock. The world soybean production increased by 4.6% annually from 1961 to 2007 and reached average annual production of 217.6 million tons in 2005-07. World production of soybeans is predicted to increase by 2.2% annually to 371.3 million tons by 2030 using an exponential smoothing model with a damped trend. Finally, three scenarios and their implications are presented for increasing supply as land availability declines. The scenarios highlight for agribusiness policy makers and managers the urgent need for significant investments in yield improving research.

Keywords: Soybean, production, yield, land use, long-term projection, exponential smoothing with damped trend

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Introduction

Soybeans *(Glycine max)* are one of the most valuable crops in the world not only as an oil seed crop and feed for livestock and aquaculture, but also as a good source of protein for the human diet and as a biofuel feedstock. Rapid soybean demand increases in the last decade challenge the reliability of supply, stock levels, and reasonable pricing. In just the past two years soybeans have topped $16.00 per bushel (July 3, 2008) and Argentina, the world's third largest producer, had a 30% reduction in output due to drought in 2009. In order to meet the demand, there are two alternatives: increase planted hectares or increase yield (tons/ha).[1] This paper examines the long range forecasts of soybean production as well as area harvested and yield using time series model and scenario analysis. The results and the accompanying scenario analysis demonstrate for policy makers and managers both the challenges of meeting demand growth with limited supplies of arable land, and the need for public, private, and farmer investments to increase yields.

Increasing soybean hectares by: substituting for other crops (e.g. sunflower in Argentina or cotton in the United States); utilizing pasture (e.g. Santa Fe, Argentina or Mato Grosso, Brazil); or replacing native vegetation (e.g. cerrado in Brazil) has been the most expedient manner to increase soybean output. World soybean production increased 36% since 2000 (Figure 1). World-wide soybean harvested acres though increased 28% and drove 81% of the increased production. Yield increased only six percent since 2000 and contributed only 19% to the increase. Going forward available farmland for soybean production will be limited by decreasing quantities of land not already in production, increased farmland loss for urbanization, heightened sensitivities about agricultural uses of land, and weak property rights in regions such as Africa that constrains the employment of modern agricultural methods (Goldsmith 2008b).

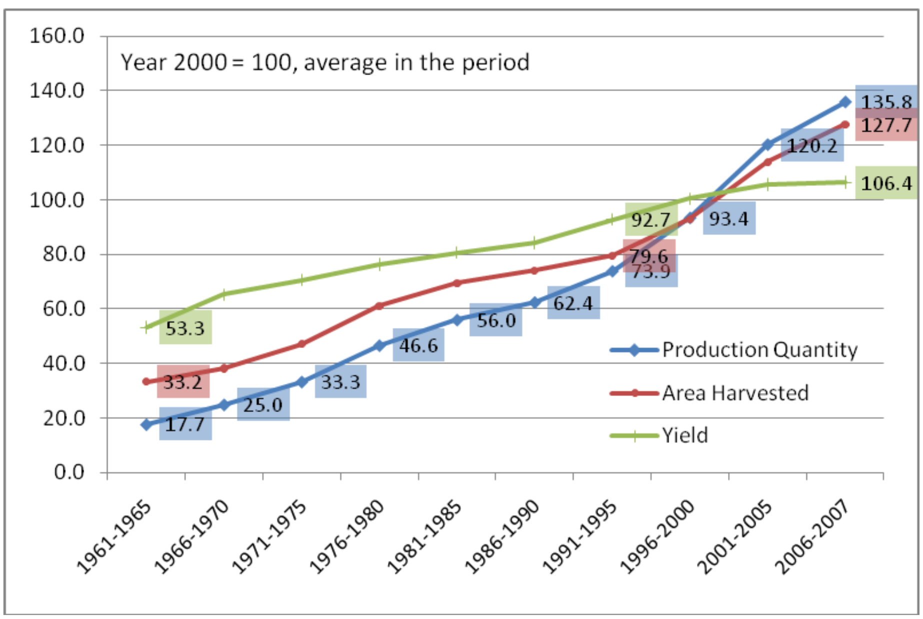

Figure 1. World Soybean Production and Area Harvested: 1961-2007
Source: FAOSTAT and authors' calculation.

[1] Reducing losses also increases the available supply, but would have minor impact on the overall supply-demand balance.

This paper has four objectives: 1) examine the contribution of increased land use as a component of overall production; 2) analyze the contribution of yield to overall production across major producing countries; 3) estimate the long range production quantities of soybeans at country and international levels; and 4) use scenario analysis to help policy makers and mangers think about the implications of these trends on policy and strategy.

Soybean Production: Historical View (1961-2007)

Production

The world annually produced 28.6 million metric tons of soybeans in 1961-65, and reached 217.6 million metric tons in 2005-07. The quantity increased 7.6 times during the half century. The USA produced more than 50 percent of the world soybean production until the 1980s but that share has declined to 37.0% in 2005-07(Figure 2). Brazil and Argentina though have significantly increased their shares steadily over the same period. Brazil is the second largest producer with 53.9 million tons, or 24.8% of world production. Argentina ranks third producing 41.4 million tons and 19.0% of world output. The top five countries; United States, Brazil, Argentina, China, and India, produce more 92% of the world's soybeans.

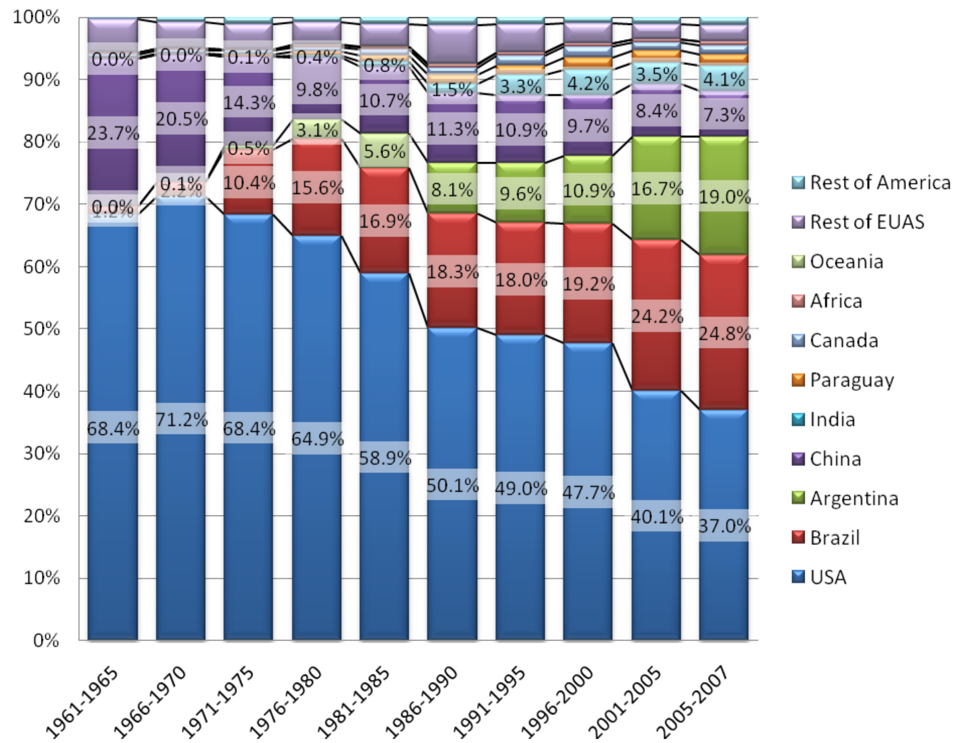

Figure 2. Shifts of Soybean Production Shares of Top 7 Countries plus Continents
Note. 5-year average. 2005-2007 is the three-year average.
Source: FAOSTAT and authors' calculation.

Land Use

The area harvested rose significantly with the dramatic increase in production outside the United States. The world soybean area harvested approximately quadrupled from 24.7 million ha in 1961-65 to 94.1 million ha in 2005-07. During the half century, the USA and China decreased their shares of soybean area harvested to 31.7% (29.9 million ha) and 9.8% (9.2 million ha) respectively in 2005-07, while Brazil and Argentina increased their shares to 23.3% (21.9 million ha) and 16.0% (15.1 million ha), respectively, (Figure 3).

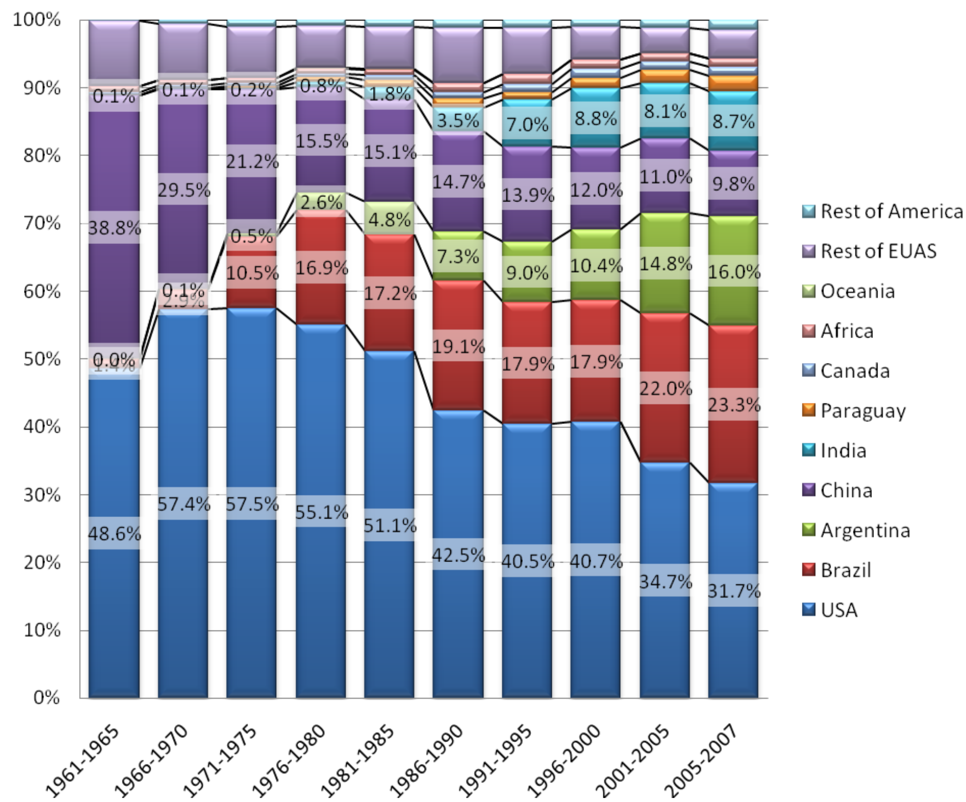

Figure 3. Shifts of Soybean Area Harvested Shares of Top 7 Countries plus Continents
Note. 5-year average. 2005-2007 is the three-year average.
Source: FAOSTAT and authors' calculation.

Yield

The world average soybean yield doubled from 1.16 metric tons per ha in 1961-65 to 2.31 metric tons per ha in 2005-07 (Figure 4). Out of the top 5 soybean production countries, Argentina reached 2.74 metric tons per ha while India produces about one metric tons per ha. The quadrupling of the area harvested and a doubling of the yield since 1961 has increased world soybean production 7.6-times. During the same period, the main production area has shifted from the USA and Asia (China and India) to the USA and South America, especially Brazil and Argentina.

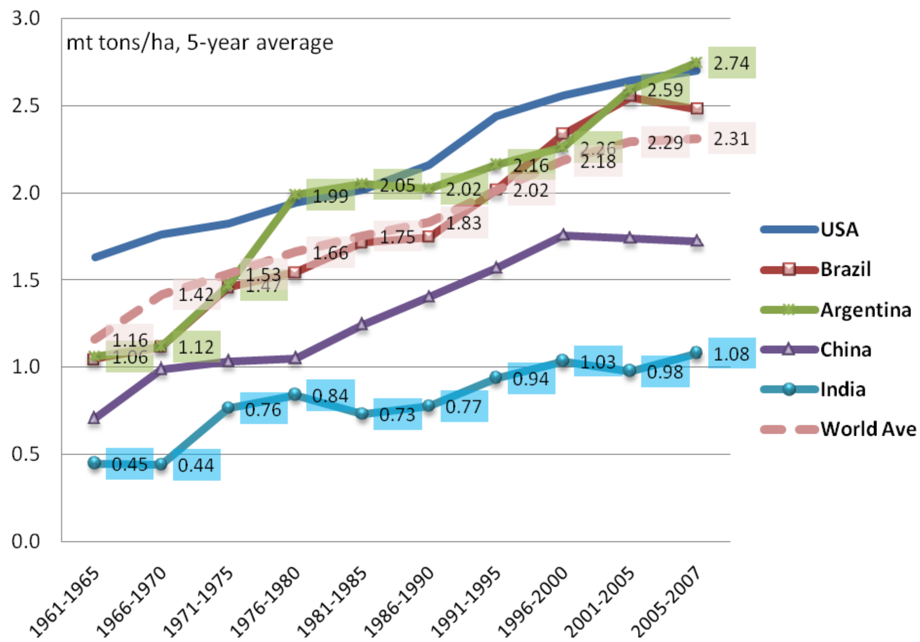

Figure 4. Changes in Soybean Yield by Country and World Average: 1961-2007
Note. 2005-2007 is 3-year average.
Source: FAOSTAT and authors' calculation.

Literature Review

A number of models have been used to forecast soybean production. Rosegrant et al. (2001) provide both baseline projections and alternative scenarios of global food supply, demand, trade, and malnutrition in 2020. Their International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model analyzes impacts on alternative scenarios but does not provide the data granularity at the country, land use, and yield levels. OECD-FAO (2009) provides only a 10-year assessment of future prospects in the major world agricultural commodity markets though 2018 and aggregates all oilseeds into one class. This does not allow focus on the special case of soybeans. The USDA (2009) also provides 10-year projections for the agricultural sector including soybean sector through 2018 but focuses on U.S. agriculture.

Box-Jenkins ARIMA (Autoregressive Integrated Moving Average) estimation provides excellent flexibility for time series forecasting not only for addressing auto-correlated errors, but exploring non-zero trends, the smoothing of trends and levels, and dampening forecast estimates. Exponential smoothing helps correct for the large fluctuations common in production data (Ferbar et al, 2009). In our case data quality is problematic and adds to large fluctuations because we require a methodology suitable for all 179 countries in our dataset. Additionally, previous research has found improved forecast performance when a dampening coefficient is employed, especially when forecast length approaches fifty percent of the historical series (Miller and Liberatore, 1993). In our case we project 23 years into the future.

Finally, when using Box-Jenkins ARIMA approach to forecast a constructed variable, in our case production as a function of area and yield, $P = A \times Y$, it is not clear whether it is better to forecast *A* and *Y* separately to produce the forecast, or to forecast *P* directly (Kennedy, 2003). While there is no conclusive evidence as to the choice between the direct forecast of aggregated variables (production, *P*) and the indirect forecasts as the product of forecasts of the components (area harvested, *A*, and yield, *Y*), indirect forecasts tend to outperform direct forecasts (Kang, 1986).

Methodology

Our overall objectives are to estimate and analyze country-level projections through the year 2030, focusing on land and yield as components of production. We forecast explicitly A and Y then produce P following Kang (1986) and consistent with Rosegrant et al. (2001 and 2002) and OECD-FAO (2009).[2] We define the following: soybean production in terms of *P* (metric tons); area harvested in terms of hectares, *A* (ha); and soybean yield, *Y* (tons/ha) as *P* divided by *A*.

This yields the following relationship:

$$P = (P/A) \times A = Y \times A.$$

Production growth rate ($\dot{P}$) is disaggregated into yield growth rate ($\dot{Y}$) and area harvested growth rate ($\dot{A}$) to obtain:

$$\dot{P} = \dot{Y} + \dot{A}.$$

Multiplying area harvested (A) and yield (Y) after estimation derives soybean production quantities (P). The two variables by country and continent are estimated individually as univariate time series (Equation 1). Box-Jenkins ARIMA type univariate time series models can be exponentially smoothed and include a damped trend in order to improve forecast performance (See Gardner and McKenzie, 1985; Hamilton, 1994; Mills, 1990). Introducing a damped trend into exponential smoothing makes sense as growth rates in yield and expansion of harvested land begin to plateau over time.

Following Gardner and McKenzie (1985) and Gardner (1985), the general damped-trend linear exponential smoothing model is as follows:

$$A_t = \mu_t + \beta_t t + \epsilon_t \quad (1)$$

where A is area harvested or yield at time t, μ_t is the level of area harvested or yield at time t, β_t is parameter at t, *t* is the time trend or year, and ϵ_t is error term at t.

The smoothing equations are:

Level: $L_t = \alpha A_t + (1-\alpha)(L_{t-1} + \phi T_{t-1})$, and

[2] We also provide the readers forecasts of direct estimation in the Appendix.

Trend: $T_t = \gamma(L_t - L_{t-1}) + (1-\gamma)\phi T_{t-1}$

where L_t = smoothed level at t of the series, computed after A_t is observed,
α = smoothing parameter for the level of the series,
ϕ = trend modification or damping parameter,
T_t = smoothed trend at the end of period t, and
γ = smoothing parameter for trend.

The error-correction form of the smoothing equations is:

$L_t = L_{t-1} + \phi T_{t-1} + \alpha e_t$, and
$T_t = \phi T_{t-1} + \alpha\gamma e_t$

where $e_t = A_t - \hat{A}_t(1)$ is a one-period-ahead forecast error.
The forecast for k period(s) ahead from origin t is:

$$\hat{A}_t(k) = L_t + \sum_{i=1}^{k} \phi^i T_t.$$

If $0 < \phi < 1$, the trend is damped and the forecasts approach an asymptote given by the horizontal linear line or plateau: $L_t + T_t\phi(1-\phi)$. The equivalent process is ARIMA (1, 1, 2)[3] process that is written as:

$$(1-\phi B)(1-B)A_t = (1-\theta_1 B - \theta_2 B^2)\epsilon_t,$$

where $\theta_1 = 1 + \phi - \alpha - \alpha\gamma\phi$, and
$\theta_2 = (\alpha - 1)\phi$.

If $\phi = 1$, the model is equivalent to the standard version of Holt's (1960) model and the trend is linear. The equivalent process is ARIMA (0, 2, 2):

$$(1-B)^2 A_t = (1-\theta_3 B - \theta_4 B^2)\epsilon_t$$

where $\theta_3 = 2 - \alpha - \alpha\gamma$, and
$\theta_4 = \alpha - 1$.

Model permutations are commonly compared using both mean squared error (MSE) and mean absolute deviation (MAD) statistics. See Gardner (1985) and Ferbar et al. (2009) for excellent applications of MAD and MSE when comparing forecast models. The MSE gives more weight to large errors and is thus a more conservative fitness criterion than the MAD. The MSE is chosen as the error measurement in this study in order to avoid over amplifying the forecast estimates for the period (2008-2030). For the damped trend, $\phi = 0.98$ is set as the default when attempting to identify the best combination of level and trend parameters (α and γ). For a few countries a lower damped default coefficient was employed as the default of $\phi = 0.98$ was too high and drove trends negative.

[3] In the general ARIMA (1, 1, 2), $-1 < \phi < 1$.

Table 1. Parameters for Exponential Smoothing

a. Area Harvested

Coutry/continent	Level	Trend	Damped	Fcst MSE*
USA	0.90	0.05	0.98	1.943E+12
Brazil	0.90	0.10	0.98	1.247E+12
Argentina	0.70	0.30	0.98	1.908E+11
China	0.90	0.05	0.98	3.777E+11
India	0.90	0.20	0.98	7.709E+10
Paraguay	0.80	0.20	0.98	1.058E+10
Canada	0.60	0.10	0.98	2.693E+09
Rest of EUAS	0.90	0.30	0.98	6.688E+10
Rest of America	0.10	0.25	0.98	1.509E+10
Africa	0.90	0.05	0.98	6.782E+09
Oceania	-	-	-	-

b. Yield

	Level	Trend	Damped	Fcst MSE
USA	0.20	0.05	0.98	4.143E-02
Brazil	0.40	0.05	0.98	4.998E-02
Argentina	0.30	0.05	0.97	8.137E-02
China	0.50	0.05	0.98	1.064E-02
India	0.60	0.05	0.98	2.393E-02
Paraguay	0.40	0.30	0.80	5.083E-02
Canada	0.10	0.05	0.95	6.781E-02
Rest of EUAS	0.90	0.05	0.98	7.888E-03
Rest of America	0.30	0.05	0.98	2.694E-02
Africa	0.90	0.05	0.98	6.704E-03
Oceania	0.40	0.05	0.98	1.004E-01

Notes. *Forecasting mean square error is minimized to determine the level and trend parameters. Sample period is 1961-2007. The number of observation is 47.

Data

Soybean production and area harvested data are provided by FAOSTAT, which is commonly used in agricultural economic analysis and for projections (e.g., OECD-FAO (2009) and Rosegrant et al. (2001)). Specifically we estimated forecasts for the 21 soybean producing countries that produce 99 % of the world's soybeans. We selected for analysis the seven top producing countries (USA, Brazil, Argentina, China, India, Paraguay, and Canada) and 4 continents (Africa, Oceania, Rest of Eurasia, and Rest of America). These seven countries represent more than 95% of world soybean production in 2005-07. We analyzed soybean production, yield, and area harvested from 1961 to 2007 for each country and continent.

Estimation Results

The world soybean production compound annual growth rate for 1961-2007 (46 periods) is, $\dot{P} = \left(\frac{216.144}{26.882}\right)^{\left(\frac{1}{46}\right)} - 1 = 4.6\%$, and can be disaggregated into $\dot{A}$ = 3.1 % and $\dot{Y}$ = 1.5 %. In the long term, of the 4.6% annual growth in tonnage produced, the increase in yield accounted for 1.5%, or 33% of the growth in production. After 1990s, however, the contribution of yield growth to production growth declined. The compound annual growth rates of world average soybean yield were 1.4 % in 1990-95 and 1.3% in 1995-2000, then 0.0% in 2000-05 and -0.9% in 2005-07 (Figure 5). The world soybean production growth rates during the above four periods (3.2%, 4.9%, 3.8% and 0.4%) are supported by the area harvested growth rates (1.8%, 3.5%, 3.8%, and 1.3%).

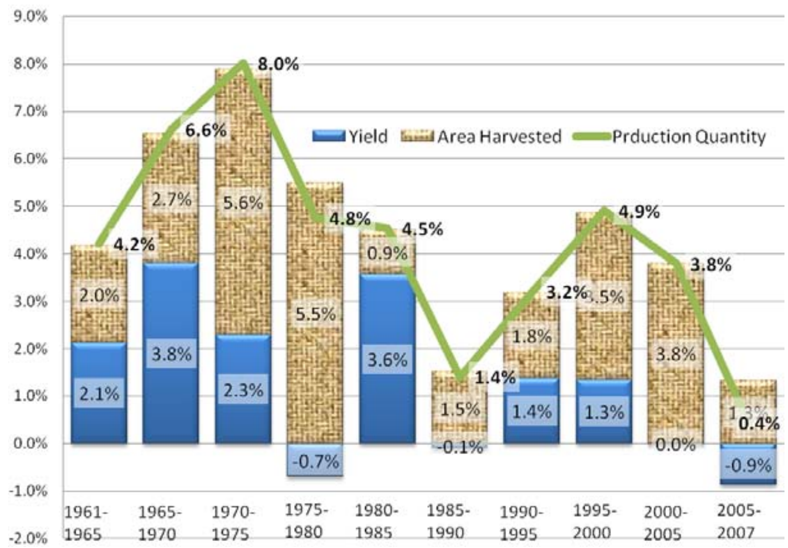

Figure 5. Annual Growth* of World Soybean Production, Area Harvested, and Yield
Notes. *Compound Annual Growth Rate = $\left(\frac{Ending\ Value}{Beginning\ Value}\right)^{\left(\frac{1}{\#\ of\ periods}\right)} - 1$.
The production growth rate is disaggregated into area harvested and yield growth rates. 1961-65 is 4 periods. 2005-07 is 2 periods. Others are 5 periods.
Source: FAOSTAT and authors' calculation.

The world soybean production is projected at 311.1 million metric tons in 2020 and 371.3 million metric tons in 2030 (Table 2). The annual growth rates are 2.9% from 2005-07 to 2010, 2.5% from 2010 to 2020, and 1.8% from 2020 to 2030. The estimated quantity level in 2030 is approximately 1.7 times greater than that in 2005-07.

During the forecast period, Argentina's production rises rapidly by 4.5% annually from 2010 to 2020 and 2.8% from 2020 to 2030, when it reaches 108.4 million metric tons in 2030. At that time, Argentina is projected to become the top soybean grower, producing 29.2% of the world's output.

Table 2. World Soybean Production Projection Summary

a. Soybean production and share

Country/continent	metric mil tons				Share			
	2005-07	2010	2020	2030	2005-07	2010	2020	2030
World Total	217.6	243.9	311.1	371.3	100.0%	100.0%	100.0%	100.0%
USA	80.6	85.1	92.9	99.5	37.0%	34.9%	29.9%	26.8%
Brazil	53.9	60.0	78.3	94.8	24.8%	24.6%	25.2%	25.5%
Argentina	41.4	52.9	81.9	108.4	19.0%	21.7%	26.3%	29.2%
China	15.8	15.8	16.6	17.2	7.3%	6.5%	5.3%	4.6%
India	8.9	10.7	15.0	18.9	4.1%	4.4%	4.8%	5.1%
Paraguay	3.9	4.1	5.2	6.5	1.8%	1.7%	1.7%	1.7%
Canada	3.1	3.1	3.5	3.8	1.4%	1.3%	1.1%	1.0%
Rest of EUAS	5.8	6.2	8.1	9.6	2.7%	2.6%	2.6%	2.6%
Rest of America	2.7	4.1	7.4	10.1	1.2%	1.7%	2.4%	2.7%
Africa	1.4	1.6	2.1	2.5	0.6%	0.7%	0.7%	0.7%
Oceania	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%

b. Compound annual growth rate

Country/continent	Compound annual growth rate		
	2005/07-2010	2010-2020	2020-2030
World Total	2.9%	2.5%	1.8%
USA	1.4%	0.9%	0.7%
Brazil	2.7%	2.7%	1.9%
Argentina	6.3%	4.5%	2.8%
China	0.1%	0.5%	0.4%
India	4.7%	3.5%	2.4%
Paraguay	1.3%	2.4%	2.1%
Canada	0.0%	1.1%	0.8%
Rest of EUAS	1.6%	2.6%	1.8%
Rest of America	11.4%	6.0%	3.2%
Africa	4.2%	2.5%	1.8%
Oceania	-10.3%	0.9%	0.7%

Source: FAOSTAT and authors' estimation.

The United States becomes the second largest producer (99.5 million metric tons) and its share declines to 26.8%. Brazil becomes the third largest soybean producer in the world and produces 94.8 million metric tons (25.5%) of soybeans in 2030. China and India will continue to increase their production quantities to 17.2 and 18.9 million metric tons in 2030, respectively. China decreases its share to 4.6% while India increases its share to 5.1% in 2030. These top 5 countries will still produce more than 90 percent of the world soybean supply.

Out of the annual 2.5% and 1.8% production growth in the decades of the 2010s and in 2020s, the area harvested contributes 1.9% in 2010s and 1.3% in 2020s, respectively (Table 3). The world total soybean area harvested increases to 140.9 million ha in 2030, which is 1.5 times larger than the area harvested in 2005-07. Argentina and Paraguay steadily increase their soybean harvest areas and reach 31.4 million ha and 5.0 million ha, respectively, in 2030. India also increases its area harvested to 14.6 million ha. These three countries also increase the shares of area harvested in the world. Since the USA and Brazil's areas harvested increase moderately, their shares decline to 25.0% and 21.7%, respectively, in 2030.

Table 3. World Soybean Area Harvested Projection Summary

a. Soybean area harvested and share

Country/continent	**million ha**				**Share**			
	2005-07	2010	2020	2030	2005-07	2010	2020	2030
World Total	94.1	102.5	123.6	140.9	100.0%	100.0%	100.0%	100.0%
USA	29.9	31.3	33.5	35.2	31.7%	30.5%	27.1%	25.0%
Brazil	21.9	22.4	26.9	30.6	23.3%	21.9%	21.8%	21.7%
Argentina	15.1	18.5	25.6	31.4	16.0%	18.0%	20.7%	22.3%
China	9.2	9.0	9.0	9.1	9.8%	8.7%	7.3%	6.4%
India	8.2	9.5	12.3	14.6	8.7%	9.3%	10.0%	10.4%
Paraguay	2.2	2.7	4.0	5.0	2.3%	2.7%	3.2%	3.5%
Canada	1.2	1.3	1.5	1.6	1.3%	1.2%	1.2%	1.1%
Rest of EUAS	3.9	4.4	5.6	6.6	4.1%	4.3%	4.5%	4.7%
Rest of America	1.4	2.1	3.8	5.1	1.5%	2.1%	3.1%	3.6%
Africa	1.2	1.3	1.5	1.7	1.3%	1.3%	1.2%	1.2%
Oceania	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%

b. Compound annual growth rate

Country/continent	**Compound annual growth rate**		
	2005/07-2010	2010-2020	2020-2030
World Total	2.2%	1.9%	1.3%
USA	1.2%	0.7%	0.5%
Brazil	0.6%	1.9%	1.3%
Argentina	5.2%	3.3%	2.1%
China	-0.7%	0.1%	0.1%
India	3.8%	2.6%	1.7%
Paraguay	6.1%	3.8%	2.3%
Canada	1.7%	1.4%	1.0%
Rest of EUAS	2.9%	2.5%	1.6%
Rest of America	10.8%	5.8%	3.1%
Africa	2.8%	1.4%	1.0%
Oceania	-10.2%	0.0%	0.0%

Source: FAOSTAT and authors' estimation.

During the same projection period, the world average soybean yield contributes 0.6% in 2010s and 0.5% in 2020s to supply (Table 4) and reaches 2.64 tons per ha in 2030. Argentina's yield increases steadily and exceeds 3.0 tons per ha in 2020 then approaches 3.5 tons per ha by 2030. Brazil's yield reaches 3.0 tons per ha by 2030. The growth of yield in the USA, starting from a higher base, continues to increase moderately but plateaus in 2030 at 2.8 tons per hectare. The yields of China and India are 1.90 tons per ha and 1.29 tons per ha, respectively, in 2030 and both do not reach 2.0 tons per ha.

Table 4. World Soybean Yield Projection Summary

a. Soybean yield

Country/continent	metric tons / ha			
	2005-07	2010	2020	2030
World Average	2.313	2.379	2.516	2.636
USA	2.703	2.722	2.777	2.823
Brazil	2.477	2.679	2.909	3.098
Argentina	2.745	2.864	3.205	3.457
China	1.720	1.771	1.841	1.898
India	1.080	1.120	1.216	1.294
Paraguay	1.816	1.503	1.316	1.296
Canada	2.659	2.491	2.408	2.358
Rest of EUAS	1.500	1.424	1.447	1.466
Rest of America	1.876	1.923	1.955	1.981
Africa	1.154	1.222	1.350	1.456
Oceania	2.205	2.106	2.312	2.480

b. Compound annual growth rate

Country/continent	Compound annual growth rate		
	2005/07-2010	2010-2020	2020-2030
World Average	0.7%	0.6%	0.5%
USA	0.2%	0.2%	0.2%
Brazil	2.0%	0.8%	0.6%
Argentina	1.1%	1.1%	0.8%
China	0.7%	0.4%	0.3%
India	0.9%	0.8%	0.6%
Paraguay	-4.6%	-1.3%	-0.2%
Canada	-1.6%	-0.3%	-0.2%
Rest of EUAS	-1.3%	0.2%	0.1%
Rest of America	0.6%	0.2%	0.1%
Africa	1.4%	1.0%	0.8%
Oceania	-1.1%	0.9%	0.7%

Source: FAOSTAT and authors' estimation.

Scenarios

The following three scenarios highlight the interplay between land use and yield when addressing the future forecasted soybean demand of 371 million metric tons. The pressure to dedicate current or new agricultural lands to soybeans will be great unless yields can be increased. This pressure to meet demand is not simply an agricultural question of crop substitution. Societies and their governments will increasingly wrestle with preserving native biomes versus converting land to crop agriculture.

Arable land for soybeans is limited over the long run and a yield plateau appears to exist around 3.00 tons per hectare for most producing countries. Only Argentina appears to be on a trajectory to reach 3.50 tons per hectare by 2030. Specht et al. (1999) discuss the biological limit to soybean yield improvement in the USA and argues the 4.00 tons per ha milestone could be achieved by 2029 but would more likely take significantly longer. Recent research in Illinois shows little yield growth in public variety trials since 2000 (Goldsmith 2008a). The USA and Argentina currently hold the highest yields at, 2.7 tons/ha, 17% greater than the world average yield.

We propose three future yield scenarios where the forecasted production of 371 million metric tons is held constant:

- *Scenario 1:* This is the benchmark case and reflects the above forecast where world average yield increases annually by 0.5% and reaches 2.64 tons per ha. World total area harvested increases annually by 1.7% and reaches 140.9 million ha in 2030 assuming moderate yield growth (Figure 6).

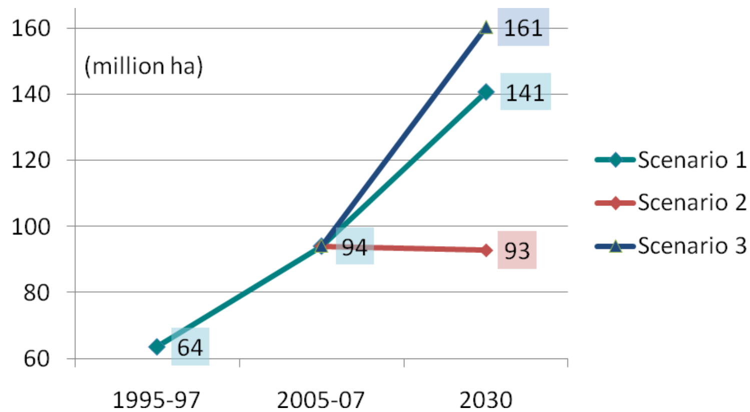

Figure 6. Scenarios for World Soybean Area Harvested and Yield to 2030

- *Scenario 2:* The "Specht" scenario imagines a high annual growth rate in yield where world average yield rising from current levels of 2.31 metric tons per hectare to 4.00 tons/ha by 2030. Such a scenario would involve significant investment in agricultural research, but would lead to large dividends in terms of reducing land use pressures to meet growing demand.

- *Scenario 3:* This scenario is pessimistic in that the annual yield growth rate slows from the forecasted level of 0.55% per year to 0.00% per year. Reduced levels of agricultural research investment occur as public priorities shift, say to alternative crops, or private priorities follow crops with higher returns on investment. Numerous authors have identified monopoly rents arising from patent, trademark, and trade secret practices as a key driver in seed innovation and associated productivity gains in agriculture (Quaim and De Janvry, 2003; Lapan and Moscini, 2004; Endres and Goldsmith, 2007). Weak intellectual property (IP) rights directly challenge the formation of monopoly opportunities and incentives for private sector investment. Private seed firm research investments are diverted from IP vulnerable crops such as soybeans to an IP protected crop[4] such as maize (Goldsmith et al., 2006). Thus differing returns to research across crops dramatically affect private investment flows and resulting productivity growth rates. Public or farmer led investment may then be necessary to fill the void where public priorities for investment remain high but private incentives are weak.

Scenario 1: Annual Yield Growth remains at its current trend of 0.55% during the forecast period

As a benchmark scenario, world average soybean yield reaches 2.64 tons/ha in 2030 when the annual growth rate of the world average yield increases 0.55% per year during the estimation period. This is the most likely case and reflects the estimation using the above damped-trend exponential smoothing model. The world total soybean area harvested grows by 1.70 % annually and reaches 140.9 million ha in 2030 to meet expected demand. Such land expansion would be 1.5 times greater than 94.1 million ha in 2005-07.

Scenario 2: Specht optimistic scenario: yield level reaches 4.00 tons/ha in 2030

Specht et al. (1999) state that the United States soybean yield could reach 4.00 tons per ha by 2029. Accelerating investments in genetics, cultural practices, and technology transfer mechanisms, combined with a focus on low-but potentially high yield settings, would be necessary to achieve these goals. Currently (2005-07 average) the soybean yields in the USA, Brazil, and Argentina are 2.70, 2.48, and 2.75 tons per ha, respectively. On the other hand, China and India's yields are 1.72 and 1.08 tons per ha, respectively. To reach the 4.00 tons per ha target, the average yield growth needs to accelerate from its base level of 0.5% to 2.3% per year. During the period, the world total soybean production increases annually by 2.2% and reaches 371.3 million metric tons (Table 5). Under this optimistic yield growth scenario the world soybean area harvested would decline to 92.8 million hectares thus requiring 1.3 million fewer hectares to meet demand of 371.3 metric tons in 2030.

Table 5. Scenarios for World Soybean Area Harvested and Yield to 2030

World Total/Average	**Year 2005-07**	**CAGR**	**Year 2030**	
	a		b	b/a
Production (mil. metric tons)	217.6	2.2%	371.3	1.7
Scenario 1 (estimation results)				
Area Harvested (mil. ha)	94.1	1.7%	140.9	1.5
Yield (tons/ha)	2.3	0.5%	2.6	1.1
Scenario 2 (higher yield growth)				
Area Harvested (mil. ha)	94.1	-0.1%	92.8	1.0
Yield (tons/ha)	2.3	2.3%	4.0	1.7
Scenario 3 (lower yield growth)				
Area Harvested (mil. ha)	94.1	2.3%	160.6	1.7
Yield (tons/ha)	2.3	0.0%	2.3	1.0

[4] Due to hybridization

Scenario 3: Annual yield growth slows to 0.00%

Weak intellectual property rights limit private incentives to invest in soybean research (Goldsmith et al., 2006). As well increasing demand for liquid biofuels such as ethanol makes maize investment increasingly attractive in regions such as the Midwest U.S. and Argentina where the complementarity between maize and soybeans has declined. Soybean yield growth could decline in the future with reduced soybean research and farmer investment in soybean production. Greater land expansion, though unlikely, would be needed to meet demand under such a scenario. Declining availability of land, higher productivity from competing crops, and greater sensitivity to maintain native biomes will limit the rate of soybean area expansion. Nevertheless, to meet production forecasts world soybean hectares would need to increase over 65 million hectares to 160.6 million, if yield growth fell to 0.0% per year. At that level, the world average yield would remain at 2.3 tons per ha.

Discussion and Concluding Remarks

This paper projects soybean area harvested, yield, and production quantities by major counties and by continent, using Box-Jenkins model employing exponential smoothing with a damped trend. The world soybean production is forecasted at 371.3 million metric tons in 2030. If 4.00 tons per ha in 2030 is set as the yield target, the world average yield growth needs to increase by 2.3% per year and the area harvested would decline to 92.8 million hectares in 2030 (Scenario 2). On the other hand, if the average yield growth remains at 0.0% per year (Scenario 3), approximately 160 million ha of soybean area harvested will be needed in 2030 to meet world demand.

Arable land on the globe is limited and the competition from other crops restricts soybean area expansion. The expansion of farmland will continue to be constrained as the international community values environmental stewardship and biome preservation. Since 1990 areas of arable land and permanent crops in the high growth countries of Brazil and Argentina have increased 17% or 14.5 million hectares (Figures 7 and 8). During the same period, the forest areas have decreased 9% or 47.8 million hectares.

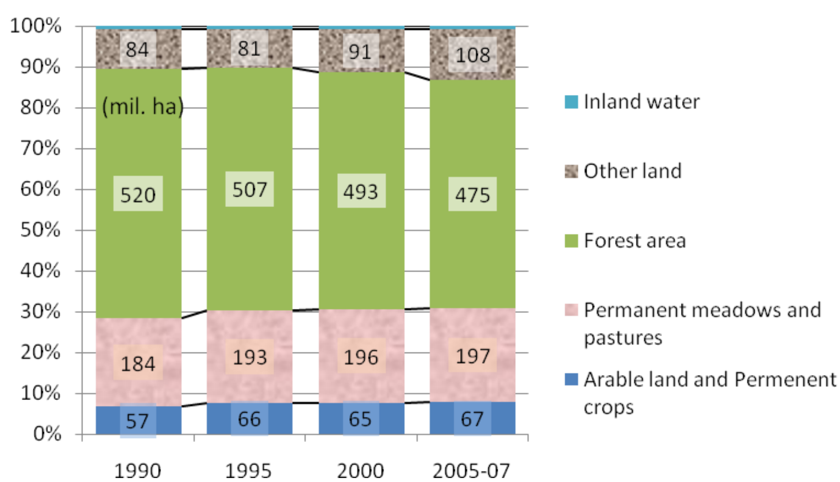

Figure 7. Land Use Changes in Brazil (1990-2007)
Source: FAOSTAT and authors' calculation.

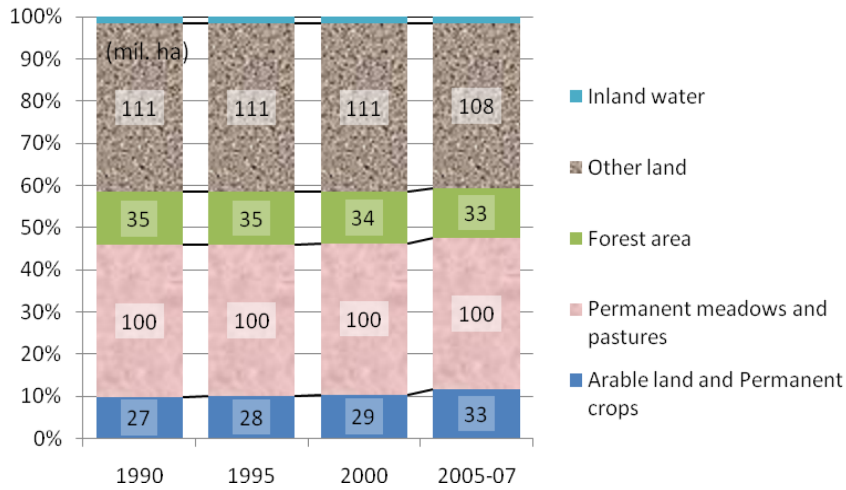

Figure 8. Land Use Changes in Argentina (1990-2007)
Source: FAOSTAT and authors' calculation.

According to the estimation results or Scenario 1, Brazil's soybean area harvested increases from 21.9 million ha in 2005-07 to 30.6 million ha in 2030 and Argentina's soybean area harvested grows from 15.1 to 31.4 million ha (recall Table 2). In 2005-07 soybean area harvested already shares 33% of the cropland in Brazil and 46% in Argentina. The soybean areas harvested under Scenario 1 is expected increase 1.4 times in Brazil and 2.1 times in Argentina by 2030. Competing crops will be crowded out, pasture will be converted, and pressure to convert native biomes will remain in such a scenario.

Therefore, policy shifts and research investment are needed to generate the yield improvements necessary to meet demand projections. Social and political pressure on land use expansion in agriculture will only accelerate in the coming years if yields continue to lag. Raising yield might take either or both of two directions: i) substantial R&D investments in genetics and agronomics in advanced soybean producing areas to achieve the biological limit, or ii) technological transfers to low-yield areas under protection of IP rights to help lower producing counties increase yields.

Acknowledgement

The authors would like to give special thanks to the anonymous reviewers for their assistance in the preparation of this manuscript.

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Appendix

Direct and Indirect Estimation Results

Following Kang's (1986) suggestion, A (area harvested) and Y (yield) were forecasted separately. Then P (production) was calculated as the product of A and Y (P=A×Y). However, according to Kennedy (2003), it is not clear whether it is better to forecast A and Y separately to produce the forecast, or to directly forecast P. The direct soybean production estimation was 362.9 million tons in 2030 (Table 6); is 8.4 million tons or 2.3% lower than 371.3 million tons of the indirect estimation result (Figure 9). Both forecasts performed comparably at the country level and each time period, thus any differences do not impede the overall results and discussion in the paper.

Table 6. Direct Estimation Results: World Soybean Production

Country/continent	**Metric mil tons**				**Share**			
	2005-07	2010	2020	2030	2005-07	2010	2020	2030
World Total	217.6	246.1	310.4	362.9	100.0%	100.0%	100.0%	100.0%
USA	80.6	82.8	90.4	96.6	37.0%	33.7%	29.1%	26.6%
Brazil	53.9	64.1	84.2	100.7	24.8%	26.0%	27.1%	27.7%
Argentina	41.4	53.7	81.2	103.7	19.0%	21.8%	26.2%	28.6%
China	15.8	16.2	17.3	18.3	7.3%	6.6%	5.6%	5.0%
India	8.9	10.5	14.0	16.8	4.1%	4.3%	4.5%	4.6%
Paraguay	3.9	4.2	4.7	5.1	1.8%	1.7%	1.5%	1.4%
Canada	3.1	3.2	3.7	4.1	1.4%	1.3%	1.2%	1.1%
Rest of EUAS	5.8	5.8	6.4	6.8	2.7%	2.4%	2.1%	1.9%
Rest of America	2.7	4.1	7.4	10.1	1.2%	1.7%	2.4%	2.8%

Africa	1.4	1.6	2.1	2.5	0.6%	0.7%	0.7%	0.7%
Oceania	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%

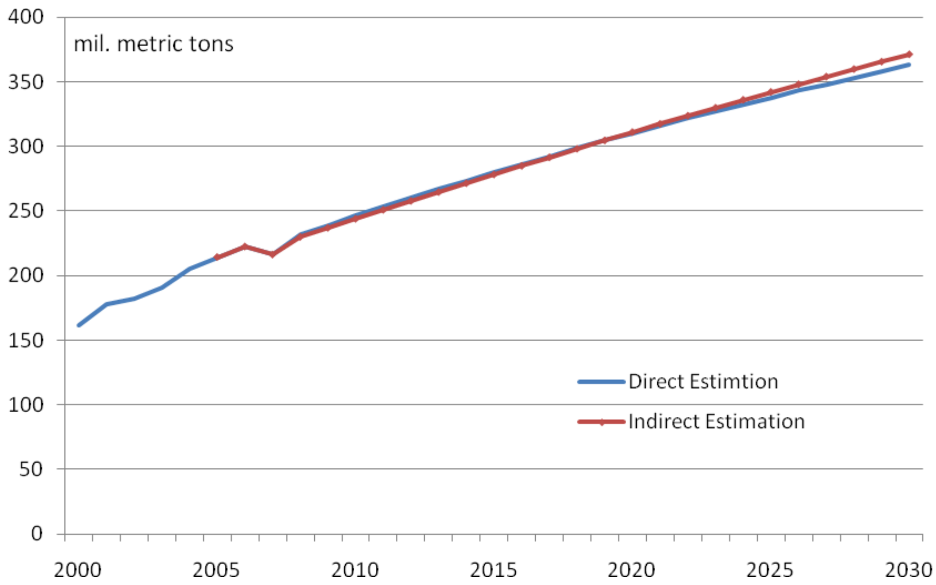

Figure 9. Direct and Indirect Estimation Results: World Soybean Production
Note. Forecasts start from 2008.
Source: FAOSTAT and authors' calculation.

