An Exploration of Agricultural Land Use Change at Intensive and Extensive Margins: Recent Evidence and Implications for Biofuels Induced Land Use Change Modeling

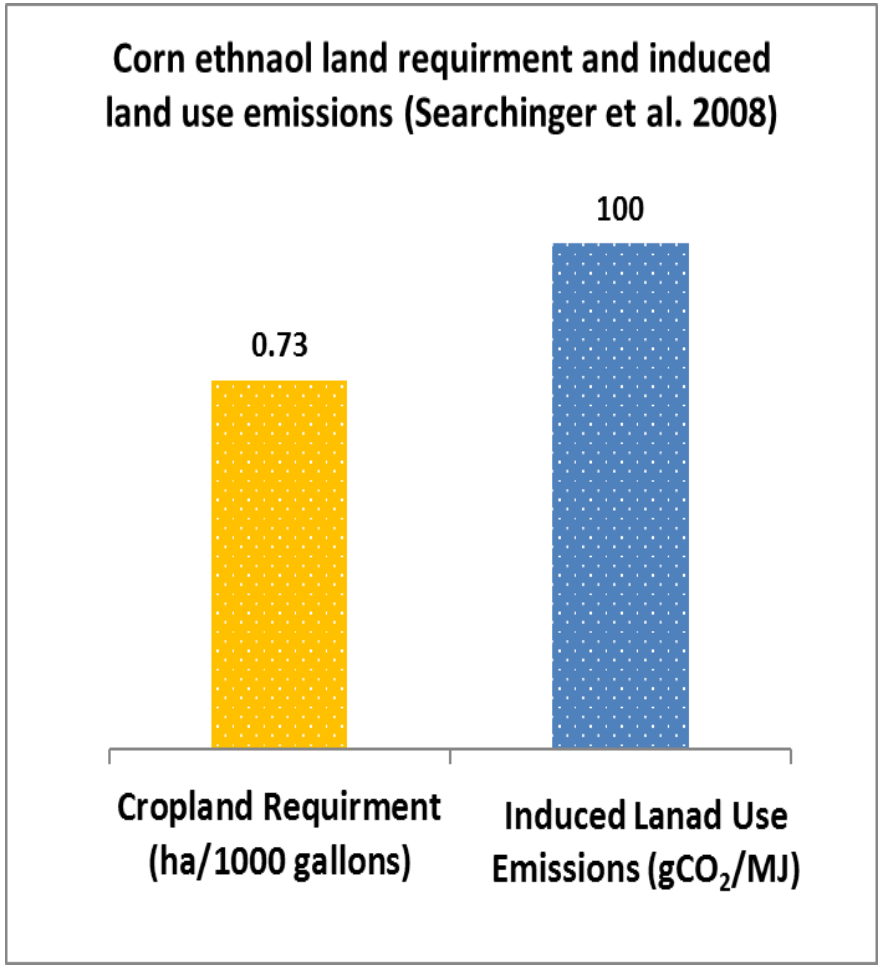
Presented by Farzad Taheripour
Based on joint research with
Wallace E. Tyner and Hao Cui

Department of Agricultural Economics
Purdue University

CRC Workshop on Life Cycle Analysis of Transportation Fuels
Argonne National Laboratory, Argonne, IL
October 24-26, 2017

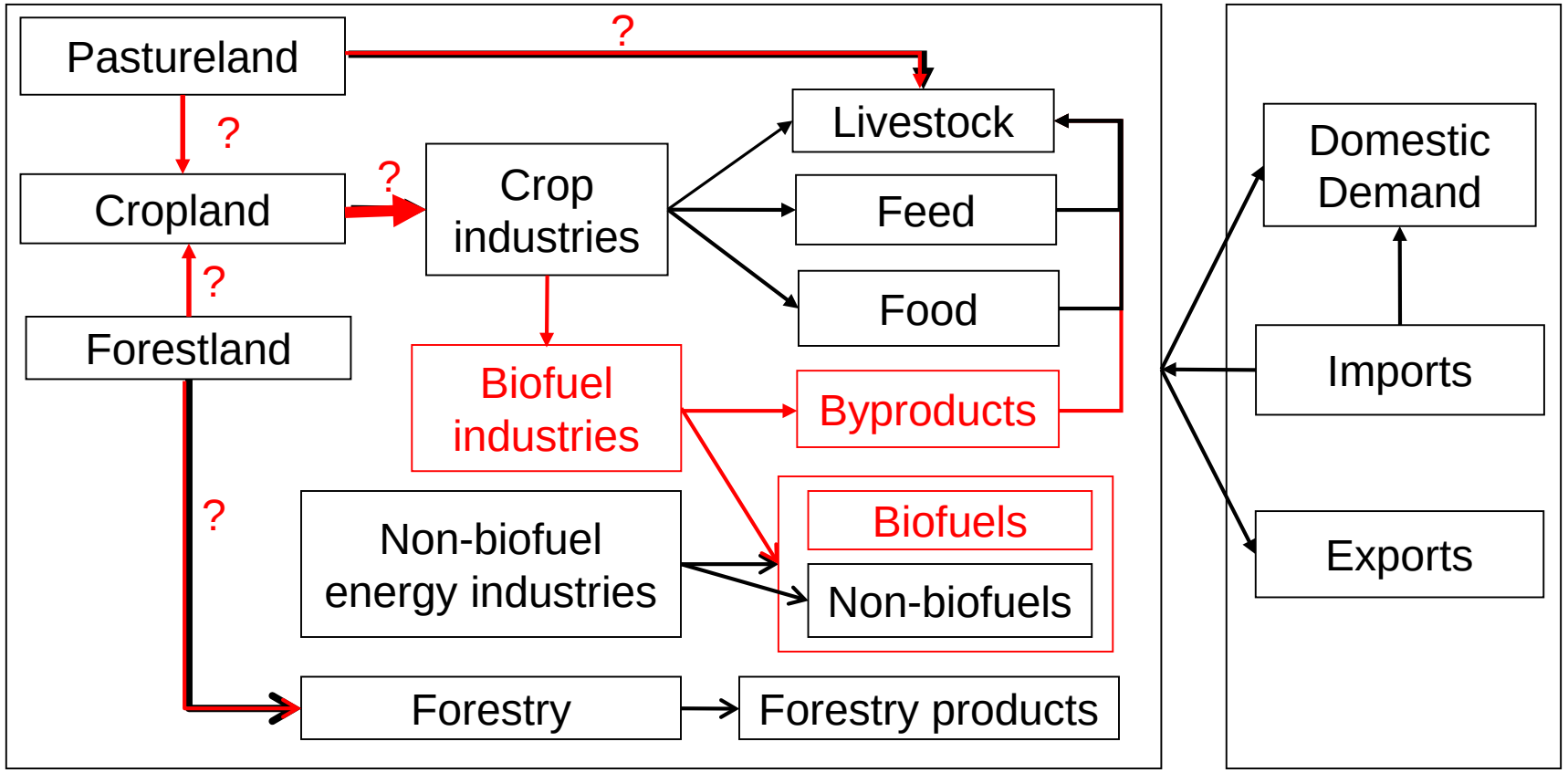
Induced land use changes: A core issue examined with advanced models

Land needed: A Simple Approach	
Ethanol yield (gallon/bushel)	2.70
Ethanol target (BG)	13.23
Required corn (billion bushels)	4.90
Corn yield in (bushel /acre)	138.20
Land needed (million acres)	35.46
Land needed (million ha)	14.35
Land needed (ha/1000 gallons)	1.08
Take into account DDGS	0.76



Why we need adv. models to study biofuel impacts?

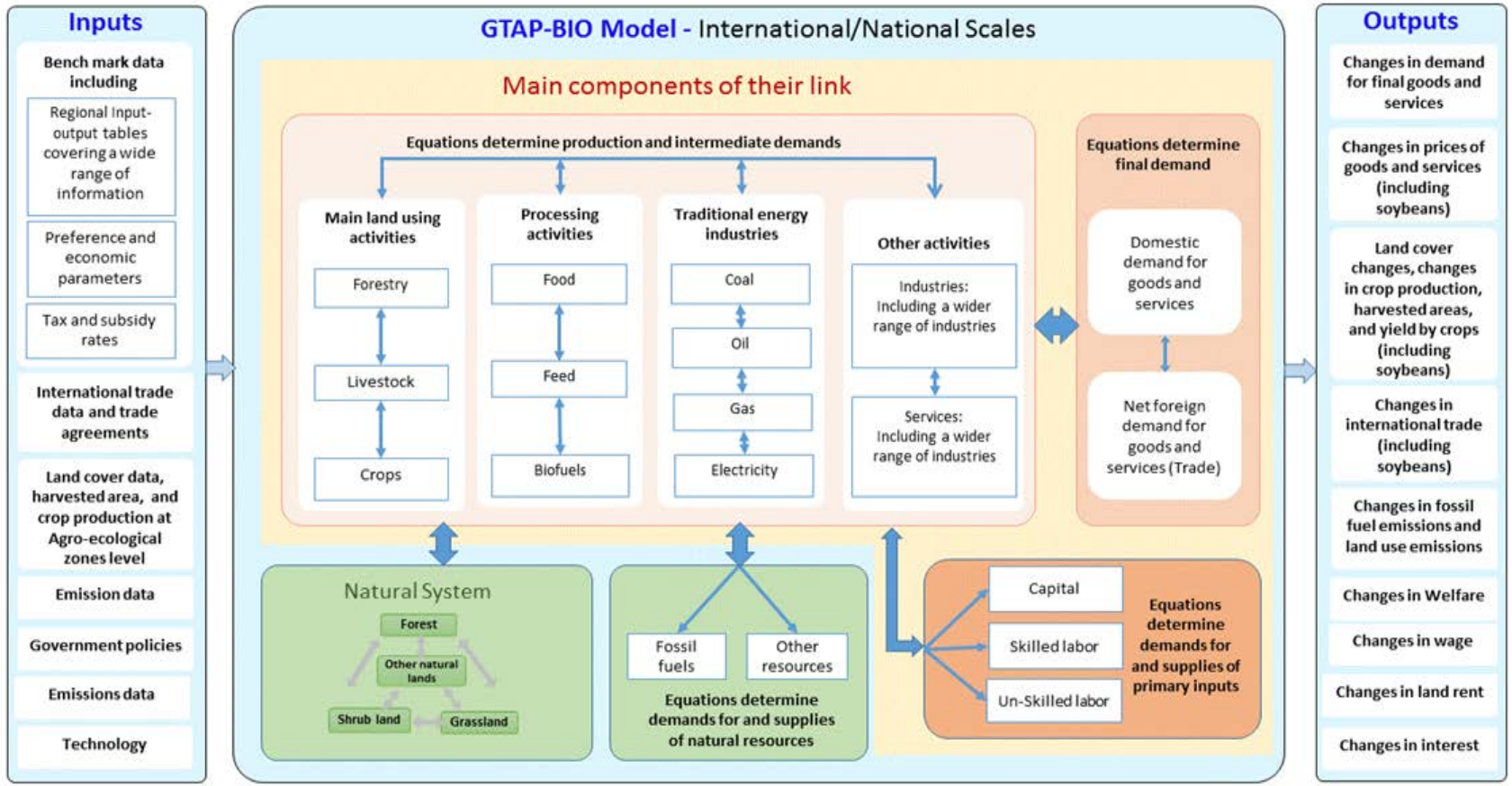
Massive production of biofuels affects many markets and regions.



Main Factors Affecting Induced Land Use Changes

- Reduction in consumption of the feedstock in non-biofuel uses,
- Reduction in consumption of non-feedstock crops,
- Switching among crops to produce more of the feedstock needed for biofuel production,
- Shifts in global production and trade of crops,
- Changes at the intensive margin:
  - To increase crop yield per hectare of harvested area: yi = Qi/Hi,
  - **To increase frequency of using cropland due to multiple cropping and/or cultivation of unused cropland: H/L.**

Calculating ILUC emissions using GTAP-BIO and AEZ-EF models



Biofuel targets

AEZ-EF model

- Biomass Carbon
- Soil organic matter
- Harvested wood
- Non-CO_2 emissions
- Forgone carbon sequestration

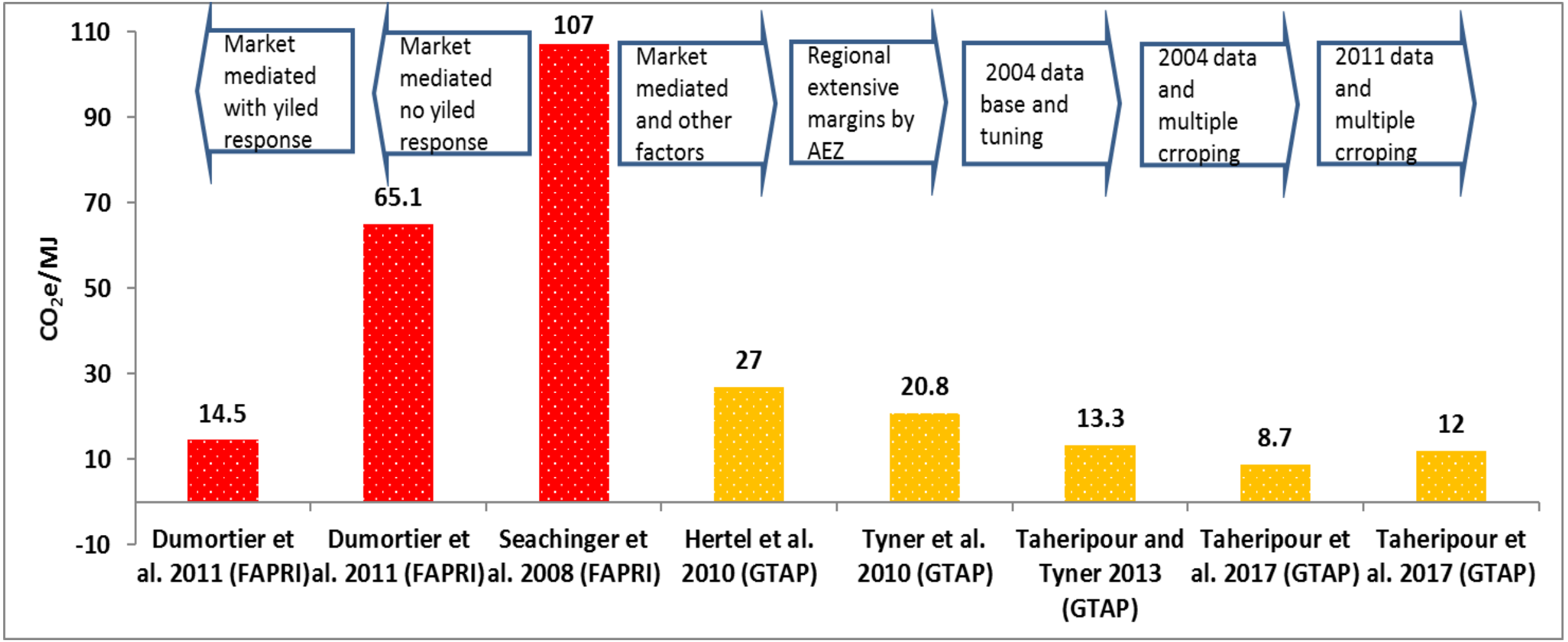
Land use emissions

History of GTAP-BIO Model and its databases

GTAP-E (2002), first model of the energy-economy-environment-trade linkages.
GTAP-AEZ (2005), land use model designed based on 18 Agro-Ecological Zones for agricultural production including crops, livestock, and forestry.
Initial GTAP-BIO (2008), combing GTAP-E and GTAP-AEZ, highlighting interactions among biofuel, livestock, and forestry, ignoring by-products.
Improved GTAP-BIO-ADV (2010), ILUC emissions due to first-generation biofuels, considering biofuel by-products and crop yield response (YDEL), variation in global extensive margin (ETA), and cropland pasture.
GTAP-BIO (2013), revisions in lands upply structure and tuning land transformation elasticities according to recent observations obtained from FAO database
Latest GTAP-BIO, improvements on the intensive margin (double cropping).

We first used database version 6, representing the world economy in 2001
We then used the data base version 7, representing the world economy in 2004
Recently we moved to version 9, representing the world economy in 2011

History of Land Use Emissions Estimates for US Corn Ethanol

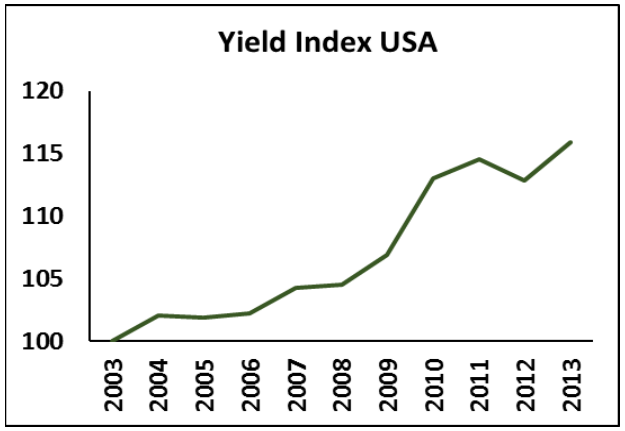


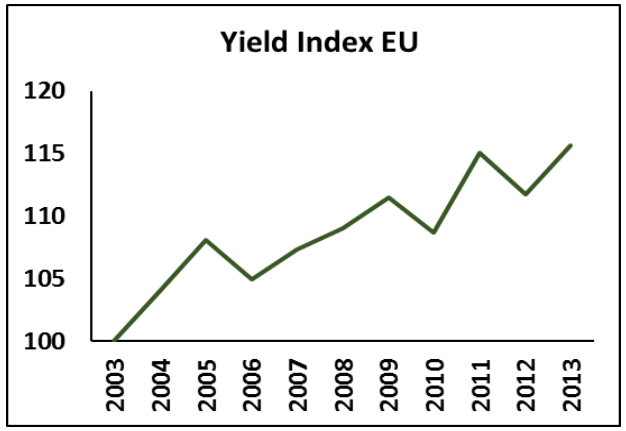
Current CARB ILUC Emissions

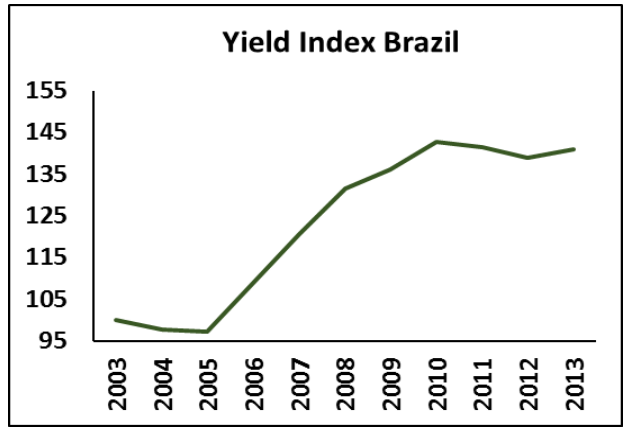
Biofuel	iLUC (gCO_2/MJ)
Corn Ethanol	19.8
Sugarcane Ethanol	11.8
Soy Biodiesel	29.1
Canola Biodiesel	14.5
Sorghum Ethanol	19.4
Palm Biodiesel	71.4

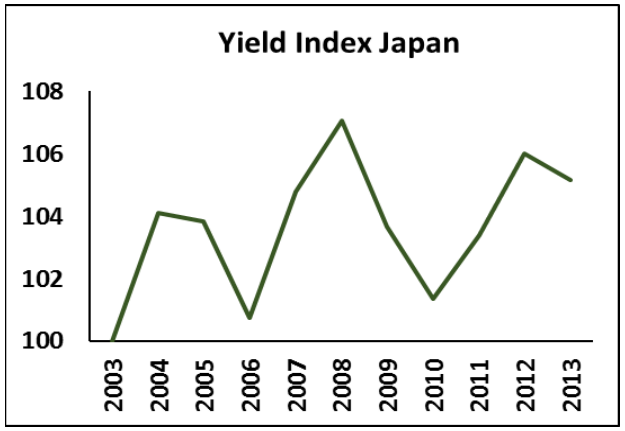
These estimates do not take into account observed land intensification in recent years

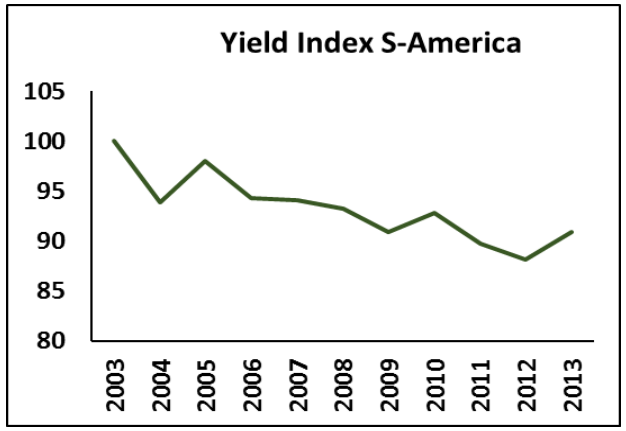
Annual % Change in Crop Yield Index in Selected Countries/Regions (2003-13)

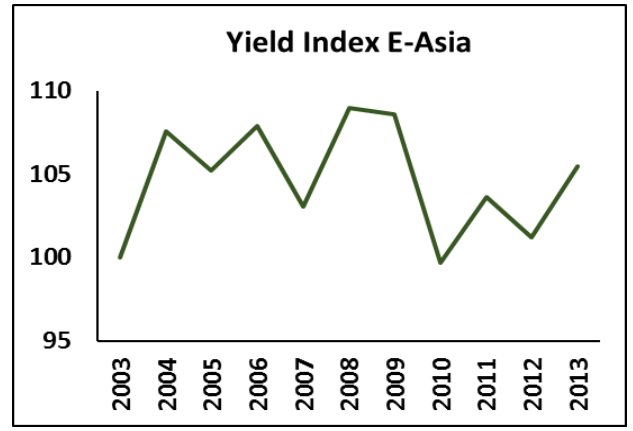


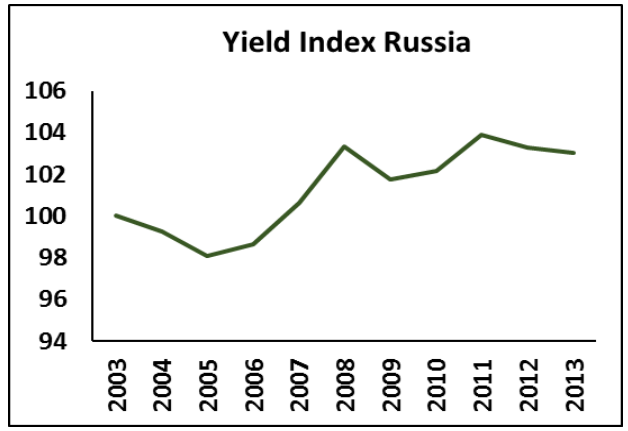




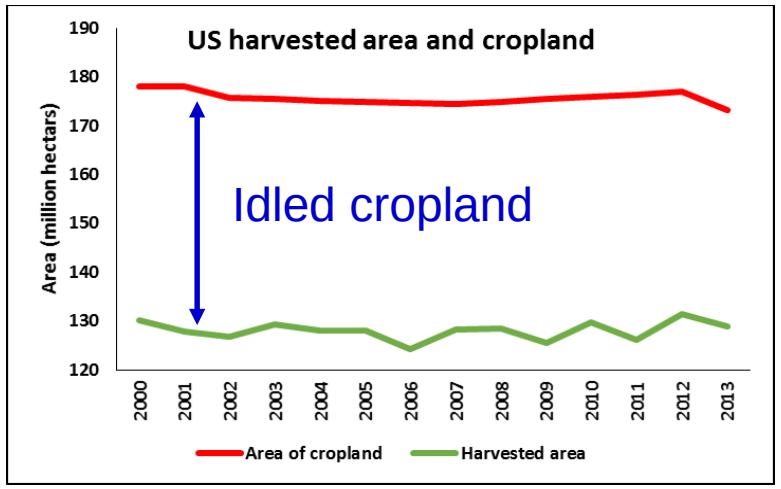


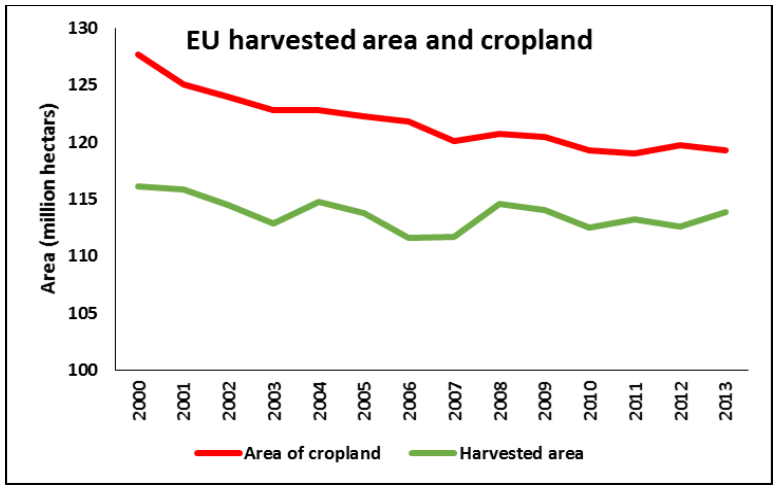


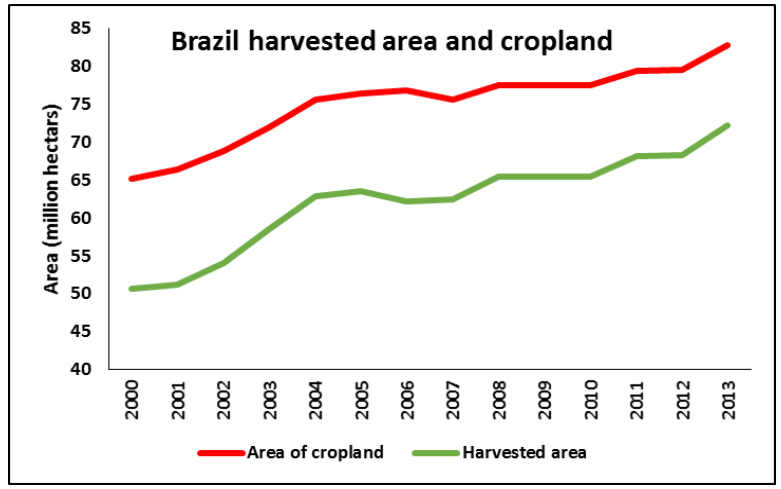


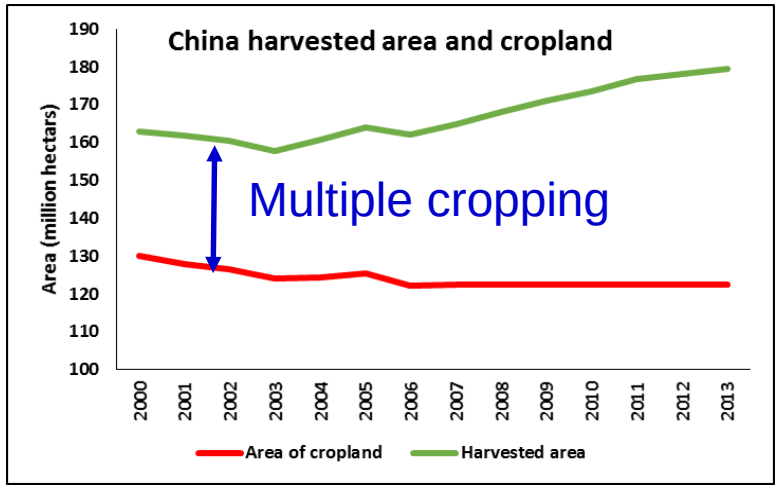


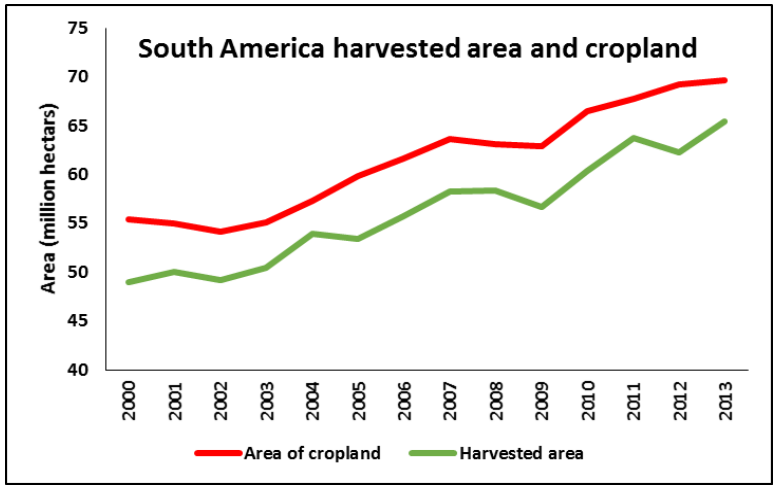
Harvested and cropland areas in million hectares (2003-13)

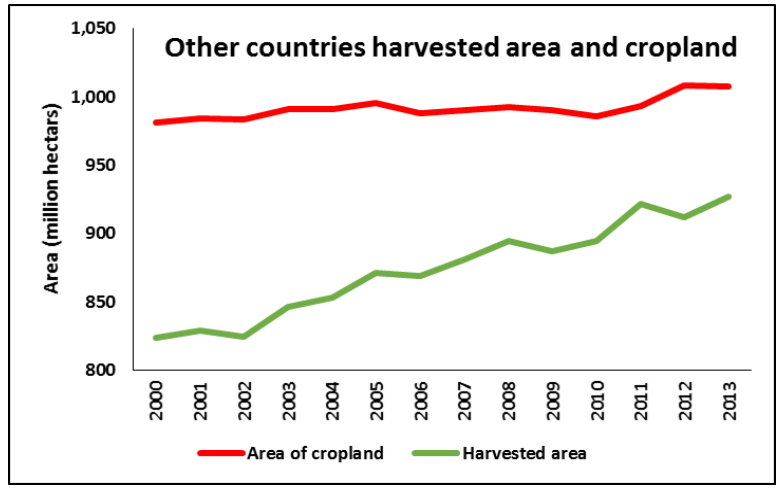












Most Recent Improvements in GTAP-BIO

- From FAO data of available cropland and harvested area for the period 2003-2013, we found that there has been more intensification (e.g., double cropping) and less extensification (changes in available cropland) in recent years.
- We have now created a new version of the GTAP-BIO model that better reflects the relative degrees of extensification and intensification by region that have actually occurred over the past decade.
- Simulations with this new model generally show lower induced land use change globally for any give biofuel shock, and also lower associated GHG emissions.

Intensification in Economic Models

- Economic models typically recognize intensification in terms of production per unit of harvested area (usually ton/ha):

  $Y = Q / H$, where Y, Q, and H represent yield, physical output, and harvested area.

- With no multiple cropping or when there is no unused cropland, changes in harvested area and changes in cropland cover over time should be identical (ignoring crop failure or data discrepancy).
- In this case, changes in yield could represent changes in intensification.

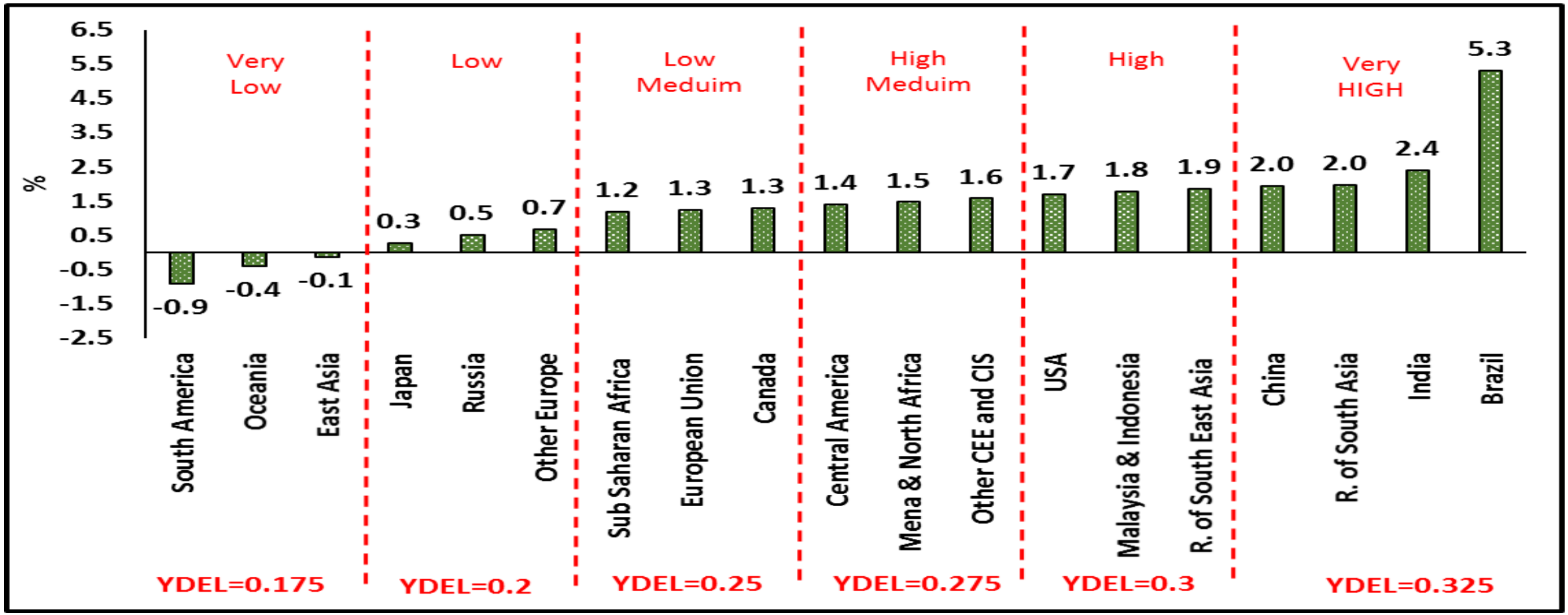
Intensification in Economic Models

- However, in the presence of multiple cropping or when there is unused cropland, economic models which do not take into account these components fail to represent intensification accurately.
- The existing economic models typically represent harvested area and assume changes in harvested area equal changes in cropland. Therefore, they misrepresent intensification and overestimate expansion in cropland cover.
- Expansion in multiple cropping and cultivating unused cropland are major sources of intensification.

Intensification in Original GTAP-BIO Model

- The earlier versions of the GTAP-BIO model, similar to other existing models, considered changes in intensification only in terms of changes in $Y = Q / H$.
- The YDEL parameter in the earlier versions of this model represents the extent to which crop yield respond to the profitability of crop production.
- This parameter is known as the yield price elasticity. The original model assumes YDEL=0.25 everywhere across the world.
- The new modified version considers changes in yield as one source of change in intensification and tuned the YDEL parameter by region according to actual observations obtained form the FAO data base.

Average of Annual % Change in Crop Yield Index (Trend 2003-13)



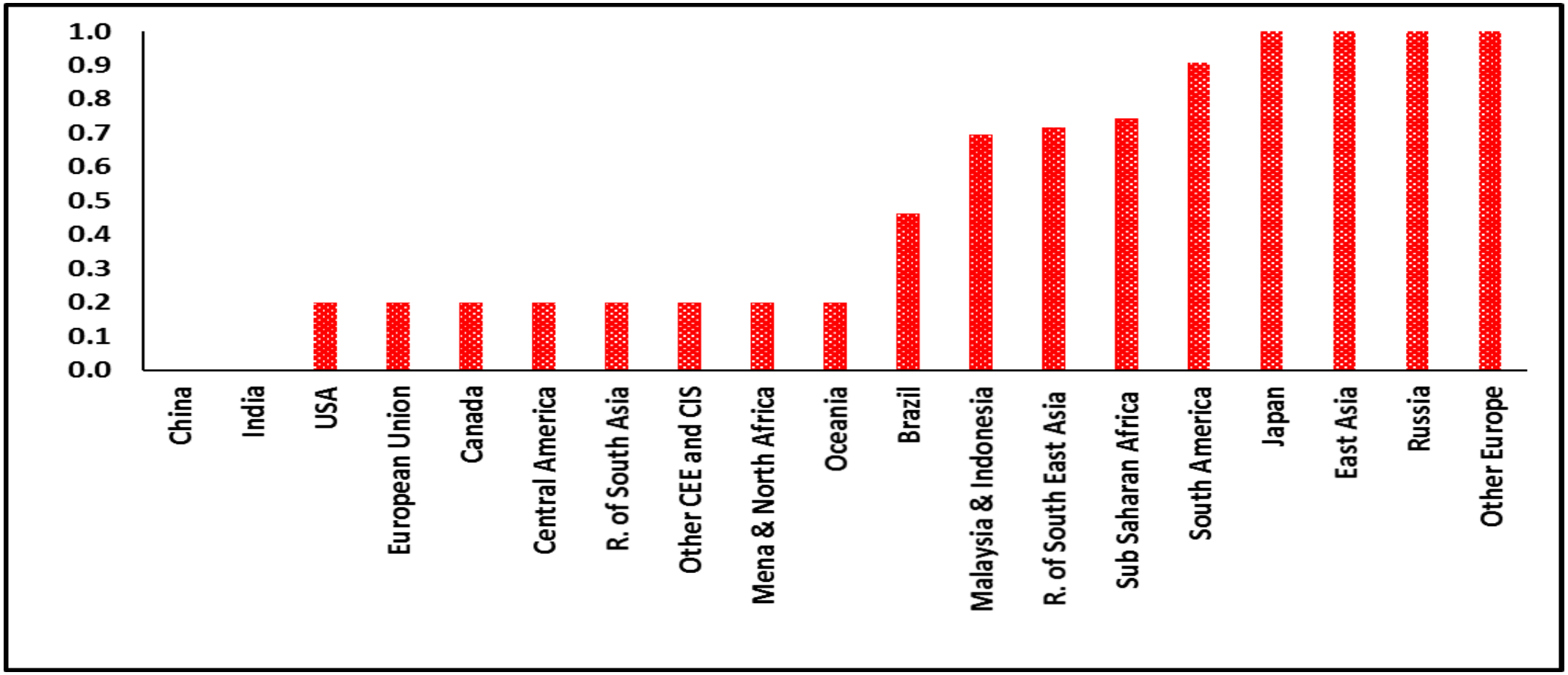
Intensification in Modified GTAP-BIO Model

- The earlier versions of the GTAP-BIO model, similar to other existing models, assume: $\Delta L = \Delta H$, where ΔL and ΔH represent change in harvested area and land cover by implementing the following equation: $\%\Delta L = \%\Delta H \times (H/L)$.
- This relationship ignores the fact that multiple cropping does exist and that there are relatively large areas of unused cropland (idled) across the world.
- The revised model modifies the above relationship and uses the following full equation: $\%\Delta L = \%\Delta H \times (H/L) + \%\Delta B \times (B/L)$, where B = L-H and represents areas of multiple cropping/idled land.
- When $B>0$, then there is idled land and when $B<0$, there is multiple cropping.
- We use actual data to determine B and its sign in each AEZ by region.

Intensification in Modified GTAP-BIO Model

- To determine $\%\Delta B$ the following process is followed:
- We define a wedge between L and H and determine its magnitude according to historical trends by region: $\gamma = [\%\Delta L] / [\%\Delta H \times (H/L)]$.
- With some exceptions, typically γ is a number between 0 and 1.
- When $\gamma = 1$ then there is no change in double cropping or no conversion of idled land to cropland. If $\gamma < 1$ then there is intensification in cropland.
- If $\gamma = 0$, all the change in harvested area is due to intensification.
- We determined γ by region using FAO data for time period of 2003-2013.
- We modified the GTAP-BIO model to handle the new approach for intensification.

Intensification in Cropland: Calibrated γ values for 2004 data base by region



Land Use Changes for Corn Ethanol – Model Comparison with 2004 data base (preliminary)

Region	Original model			New model		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	-63.2	153.4	-90.3	-12.4	30.2	-17.8
European Union	-15.9	35.0	-19.1	2.1	6.8	-8.9
Brazil	-27.8	117.1	-89.2	-21.8	26.6	-4.8
Canada	-23.0	37.0	-14.0	-1.1	6.8	-5.7
Japan	-5.3	5.4	-0.2	-5.5	5.6	-0.1
China	-0.8	82.3	-81.4	0.9	0.0	-1.0
India	-7.4	11.6	-4.1	-2.2	0.0	2.2
Central Amer.	4.0	5.6	-9.6	1.4	1.0	-2.4
South Amer.	35.7	55.7	-91.3	-9.0	46.3	-37.2
East Asia	2.1	1.7	-3.7	0.9	1.7	-2.6
Mala-Indo	0.6	2.2	-2.9	-0.6	2.1	-1.6
Rest of S. E. Asia	-12.4	14.8	-2.4	-11.4	10.7	0.7
Rest of S. Asia	-3.2	24.8	-21.6	-0.4	3.1	-2.7
Russia	12.6	11.7	-24.4	10.3	12.4	-22.7
Other CEE-CIS	-7.8	29.8	-22.0	0.9	5.6	-6.6
Other Europe	-0.3	0.5	-0.2	-0.3	0.5	-0.2
Mena-N. Afr.	0.1	23.6	-23.7	0.3	4.6	-4.8
Sub Saharan Afr.	-169.6	446.2	-276.3	-102.3	343.3	-241.0
Oceania	-0.5	18.3	-17.7	0.1	3.5	-3.6
World	-282.1	1076.5	-794.2	-150.1	510.6	-360.8

Cropland and harvested areas for Corn Ethanol – Model Comparison with 2004 data base (preliminary)

Region	Original model: Changes in 1000 ha			New model: Changes in 1000 ha		
	Harvested area	Cropland cover	Difference	Harvested area	Cropland cover	Difference
USA	153.4	153.4	0	147.3	30.2	117.2
European Union	35.0	35.0	0	33.7	6.8	26.9
Brazil	117.1	117.1	0	65.2	26.6	38.6
Canada	37.0	37.0	0	34.8	6.8	28.0
Japan	5.4	5.4	0	5.6	5.6	0.0
China	82.3	82.3	0	12.4	0.0	12.4
India	11.6	11.6	0	6.9	0.0	6.9
Central Amer.	5.6	5.6	0	4.9	1.0	3.9
South Amer.	55.7	55.7	0	48.6	46.3	2.3
East Asia	1.7	1.7	0	1.7	1.7	0.0
Mala-Indo	2.2	2.2	0	2.4	2.1	0.3
Rest of S. E. Asia	14.8	14.8	0	13.6	10.7	2.9
Rest of S. Asia	24.8	24.8	0	13.9	3.1	10.8
Russia	11.7	11.7	0	12.4	12.4	0.0
Other CEE-CIS	29.8	29.8	0	28.1	5.6	22.5
Other Europe	0.5	0.5	0	0.5	0.5	0.0
Mena-N. Afr.	23.6	23.6	0	22.3	4.6	17.7
Sub Saharan Afr.	446.2	446.2	0	422.0	343.3	78.7
Oceania	18.3	18.3	0	18.2	3.5	14.7
World	1076.5	1076.5	0	894.3	510.6	383.6

ILUC Emissions – Model and database Comparison

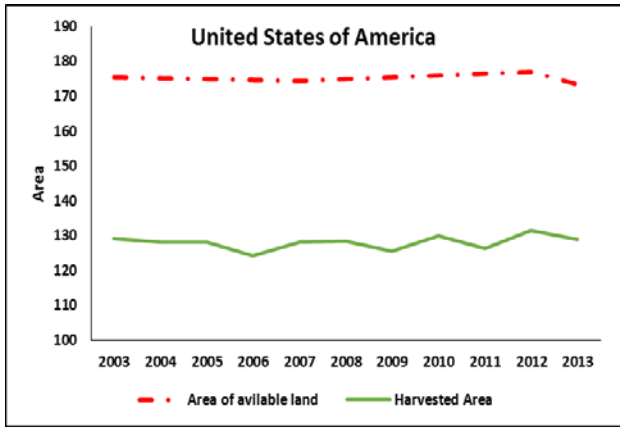
2004 database	Old Model	New Model	% Reduction
US corn ethanol	13.4	8.7	-35.1
Brazilian sugarcane ethanol	5.68	4.7	-17.3
US soybean biodiesel	21.62	16.9	-22.8
EU rapeseed biodiesel	26.55	15.7	-40.9

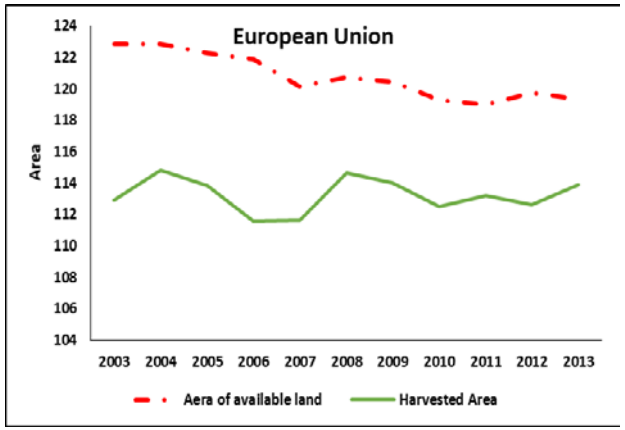
2011 database	Old Model	New Model	% Reduction
US corn ethanol	23.3	12.0	-48.5
Brazilian sugarcane ethanol	13.0	3.2	-75.3
US soybean biodiesel	25.5	18.3	-28.2
EU rapeseed biodiesel	23.7	13.7	-42.1

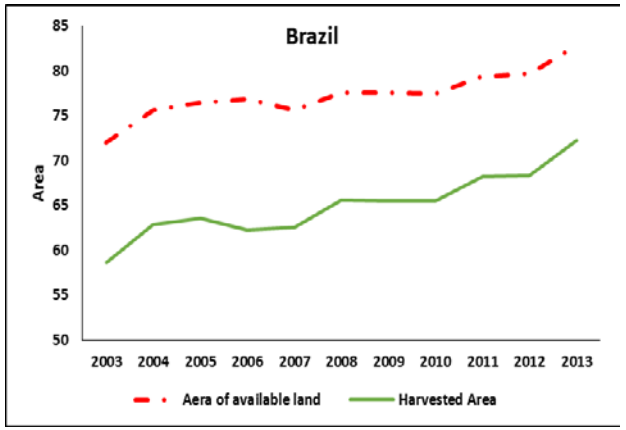
Thanks

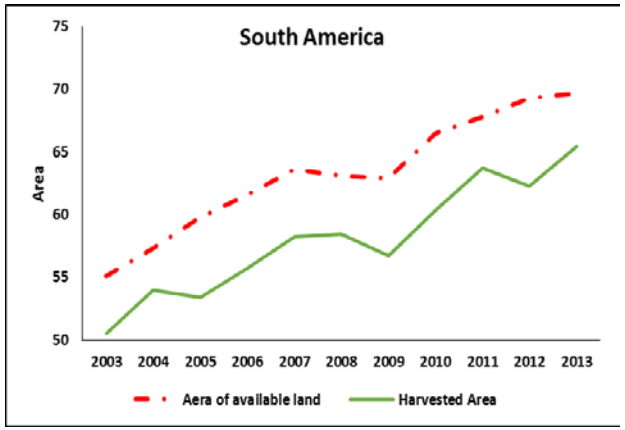
Questions and Comments

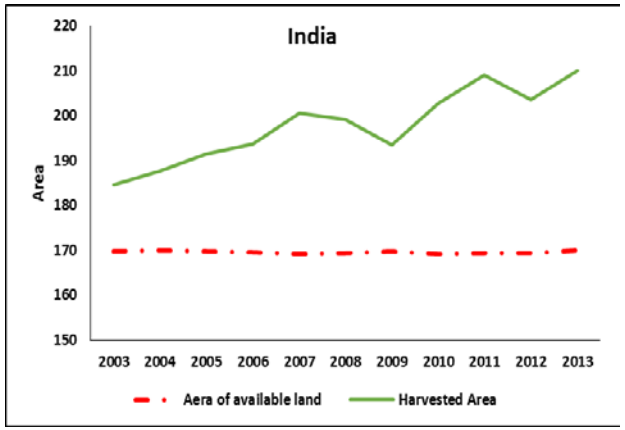
Harvested & Cropland Areas in Selected Countries/Regions in million hectares (2003-13)

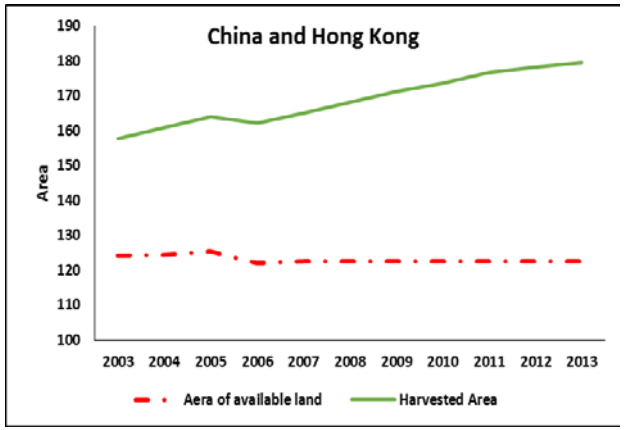


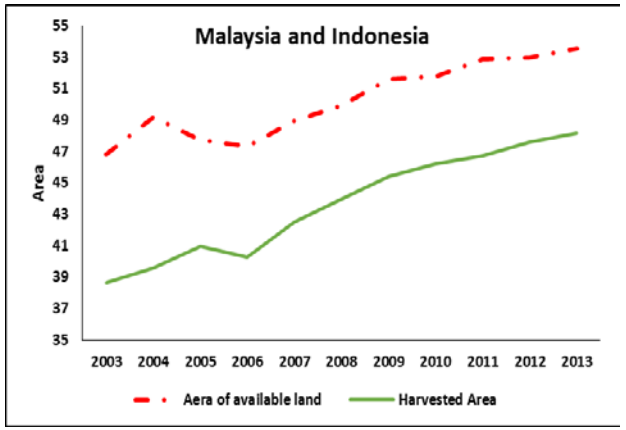


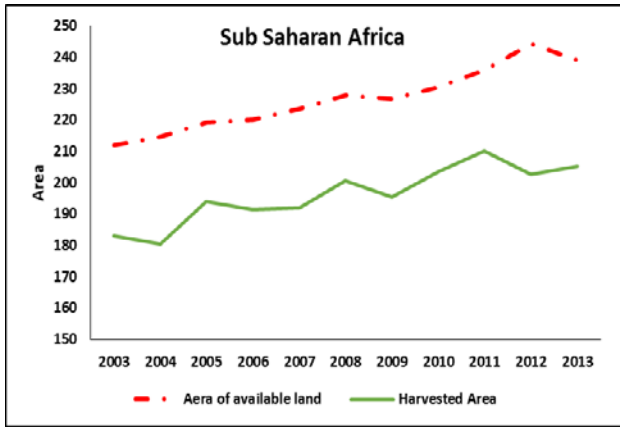




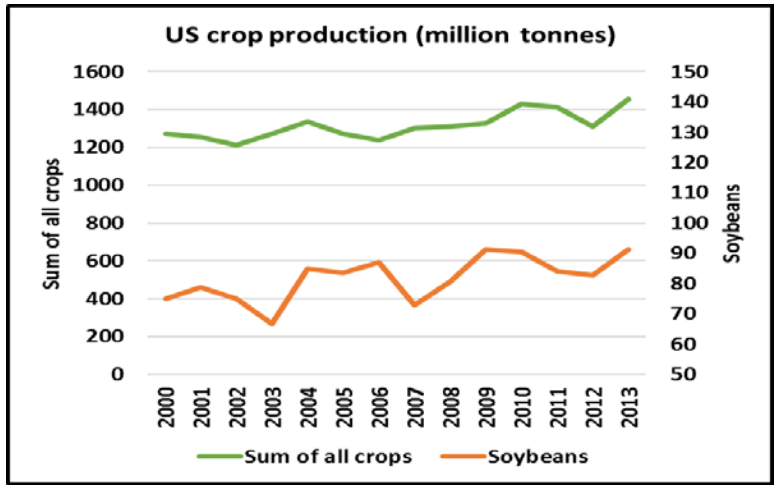


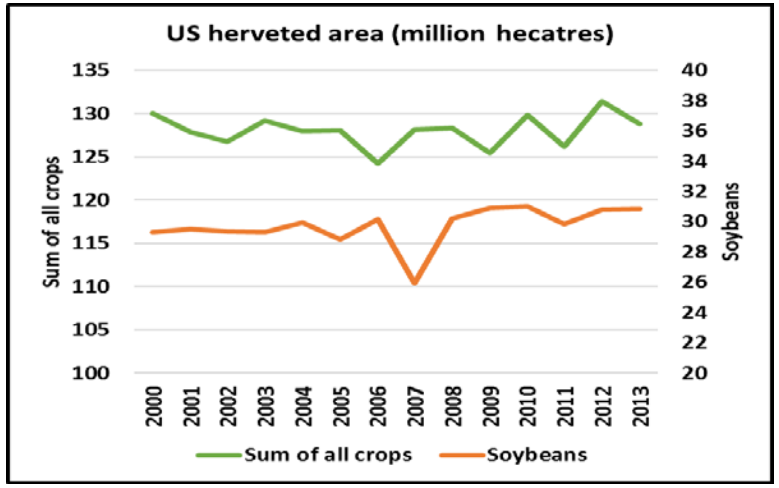


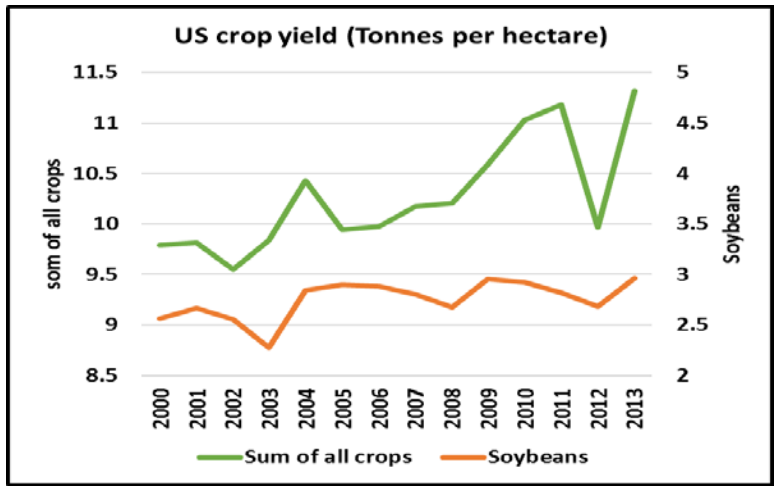


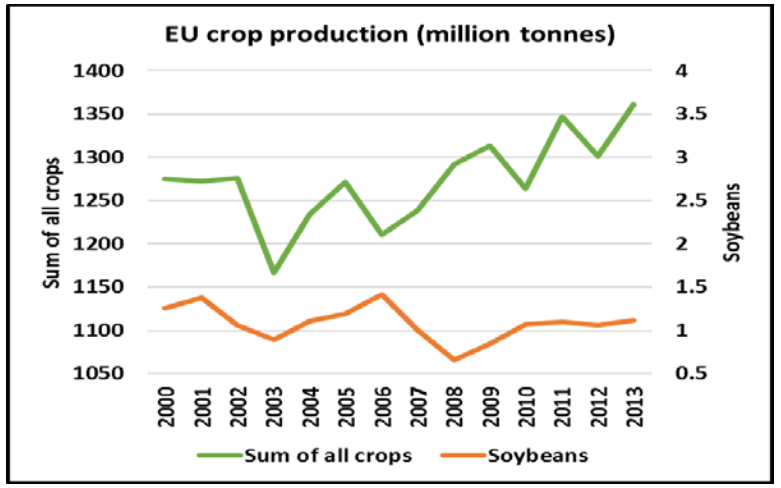


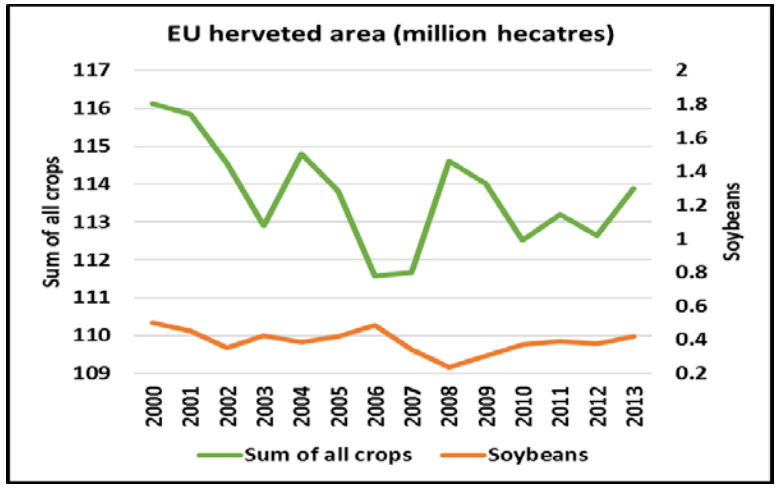
Crop production, harvested area, and yields (2000-13)

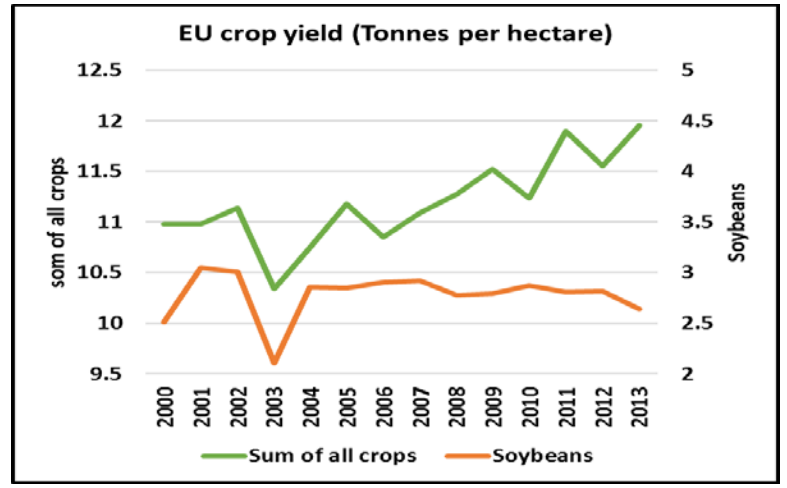




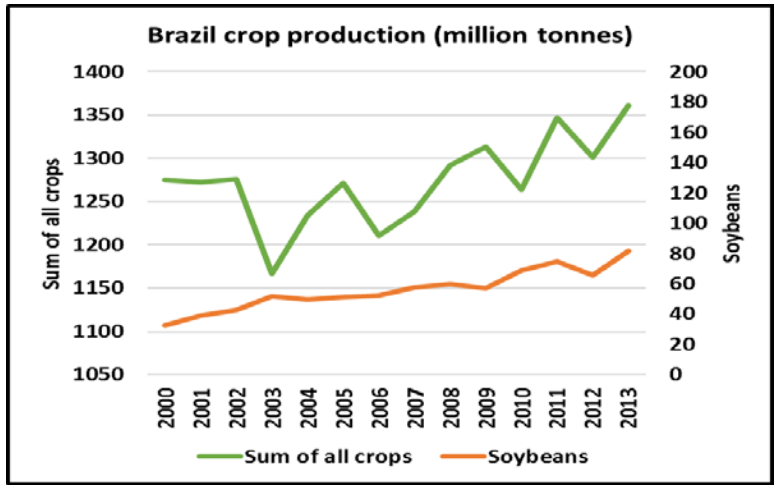


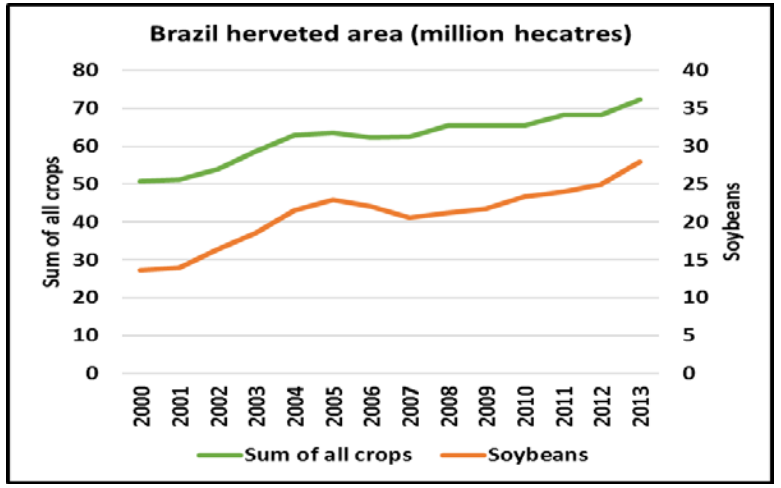


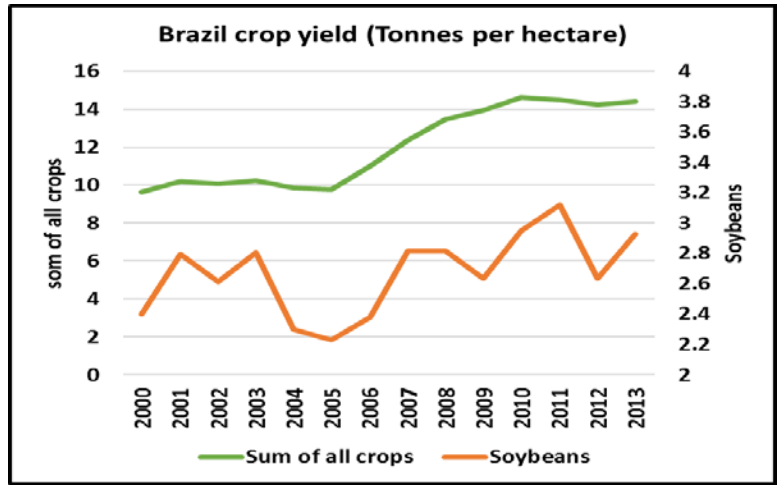


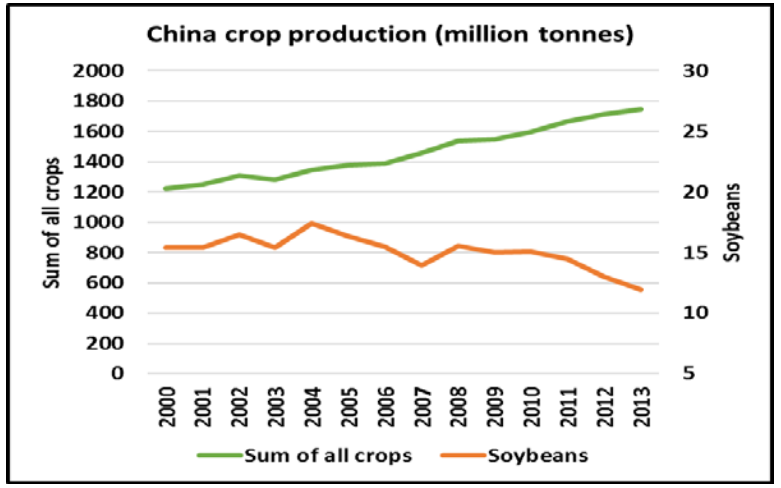


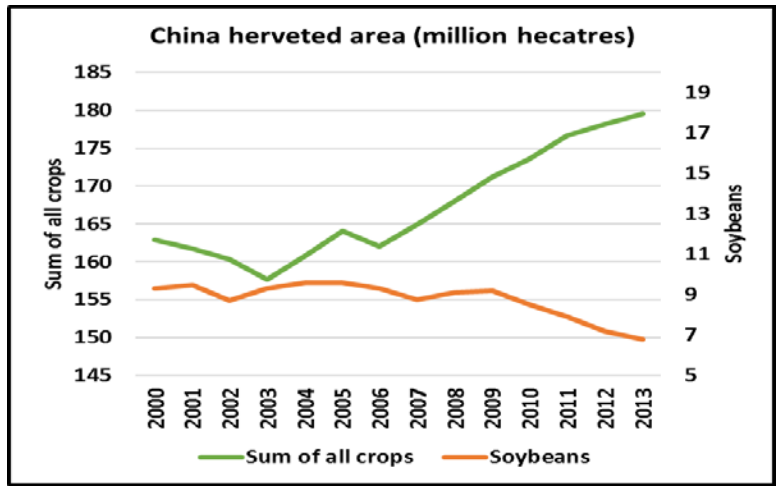
Crop production, harvested area, and yields (2000-13)

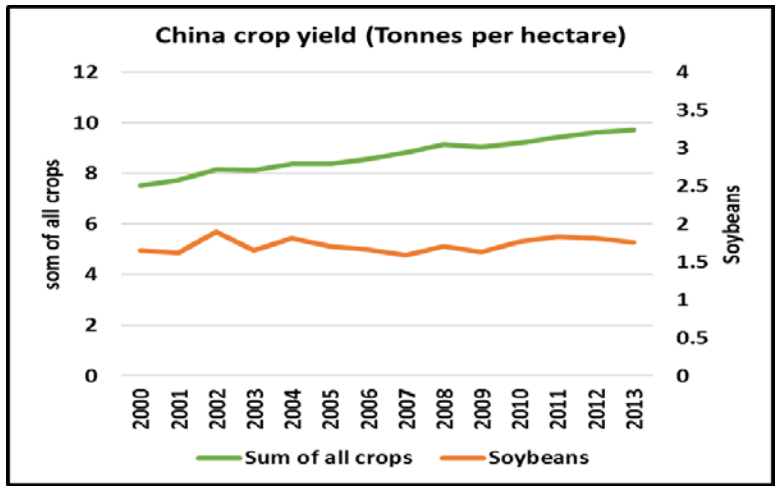












Crop production, harvested area, and yields (2000-13)