Implications of US Biofuels Production for Global Land Use

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Focus of this study

- Current US legislation calls for 17.5 billion gallons of renewable fuels by 2015; most of this is expected to be ethanol from corn (15 bill gallons)
- Until the recent corn price spike, the US appeared well on its way to reaching this target on the strength of high oil prices; now the ethanol industry is in retreat -- the mandates may become binding.
- What are the land use impacts of fulfilling the mandate? How much land might be converted to crops as a consequence? What are the GHG emissions impacts of land conversion?

Study Approach: Analytical Tool

- We utilize the GTAP global economic model adapted from Birur, Hertel, and Tyner (2007), which has following key features:
  - Treatment of biofuels follows Tyner and Taheripour: perfectly competitive industry, subject to zero profits – expansion is curtailed by rising feedstock prices
  - Incorporated into the GTAP-E global energy data base and model to establish link between energy and agr markets. Biofuels substitute imperfectly for petroleum products.
  - Explicit modeling of co-products from ethanol and biodiesel (Taheripour et al); this makes a big difference!
  - Addition of Agro-ecological Zones (AEZs) captures competition for land across uses (Hertel et al.)

Model Validation and Scenarios

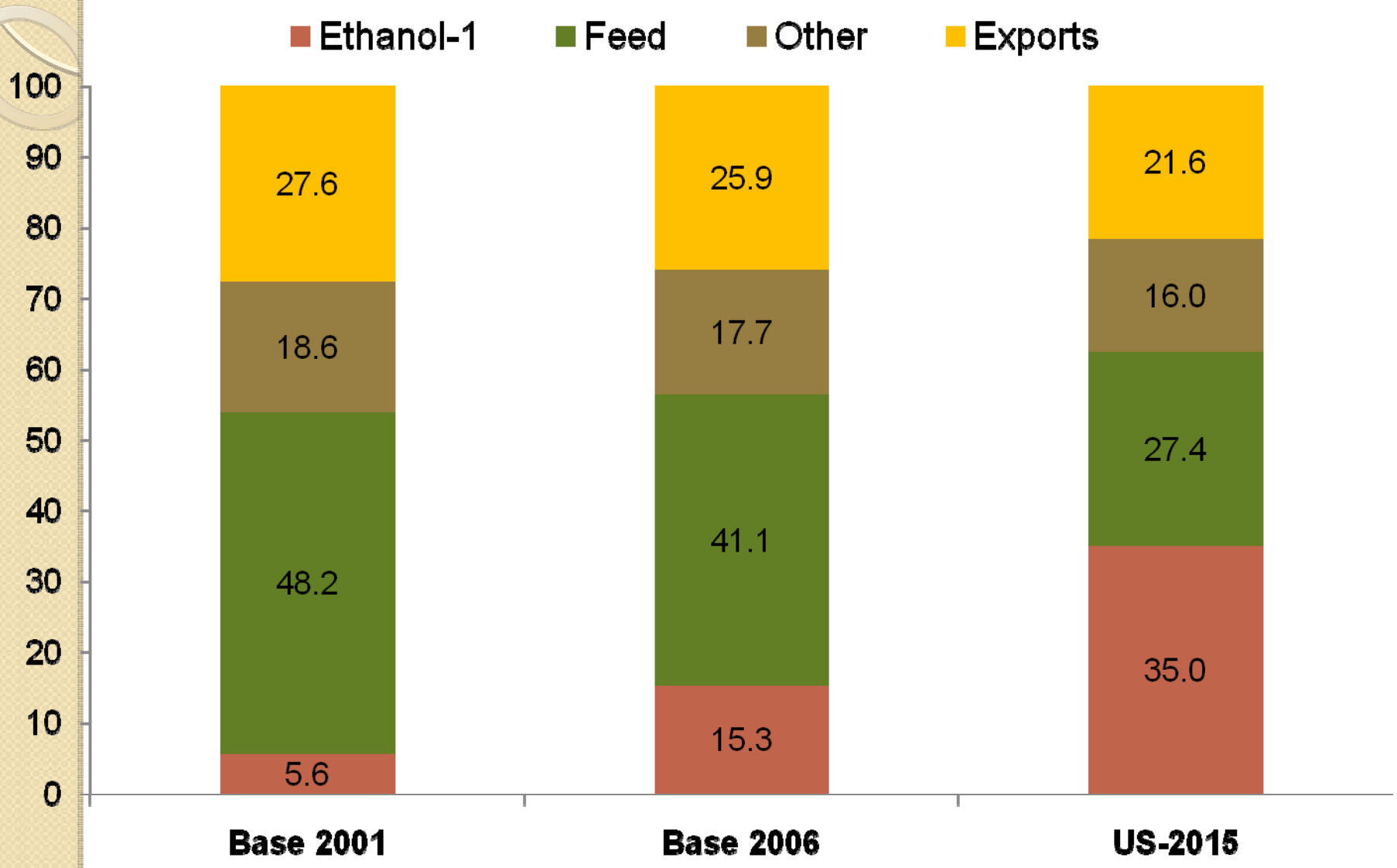
- The initial data base pertains to year 2001; hence, we perform an historic simulation to project biofuel economy in 2006, and to validate the model. Shocks include:
  - Increasing the world price of petroleum
  - Replacing MTBE with ethanol in gasoline additives in the US
  - Adjusting AVE of ethanol and biodiesel subsidies in US, EU
- Scenarios – US Mandate only:
  - Oil price rises to $115/barrel; mandate becomes non-binding
  - Oil price returns to $60/barrel, implementation of 2015 RFS
  - Oil price returns to $60/barrel, *corn only mandate* to 15 bill
  - Oil price rises to $107/barrel (13 billion gallons corn ethanol) followed by *corn only* mandate to take this to 15 billion gallons
  - *Corn only* mandate: 2001 – 2015 (1.75 to 15 billion gallons)

Biofuel Mandates in the US

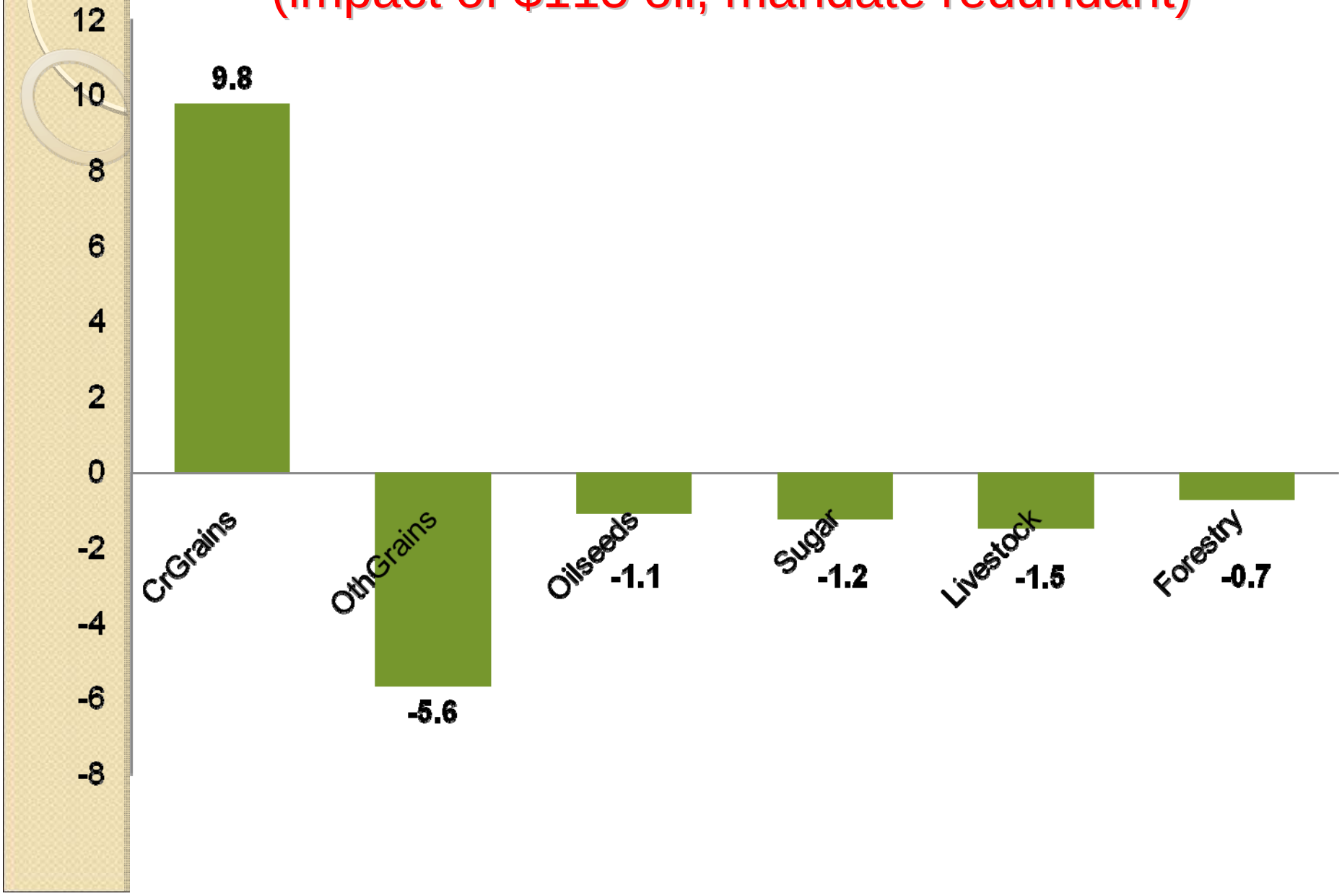
	US		
Fuel Consumption:	**2001**	**2006**	**2015**
Liquid fuels for Transport:			
Petroleum (*Quad Btu)*	25.96	27.57	29.63
Total Biofuels (*Quad Btu*)	0.150	0.503	1.519
Ethanol (*Quad Btu*)	0.149	0.471	1.390
Biodiesel (*Quad Btu*)	0.001	0.032	0.129
Share of biofuels in liquids for transport (*%*)	**0.58**	**1.83**	**5.13**

Change in Share:	2001-2006	2006-2015
Total Biofuels	1.25%	3.30%

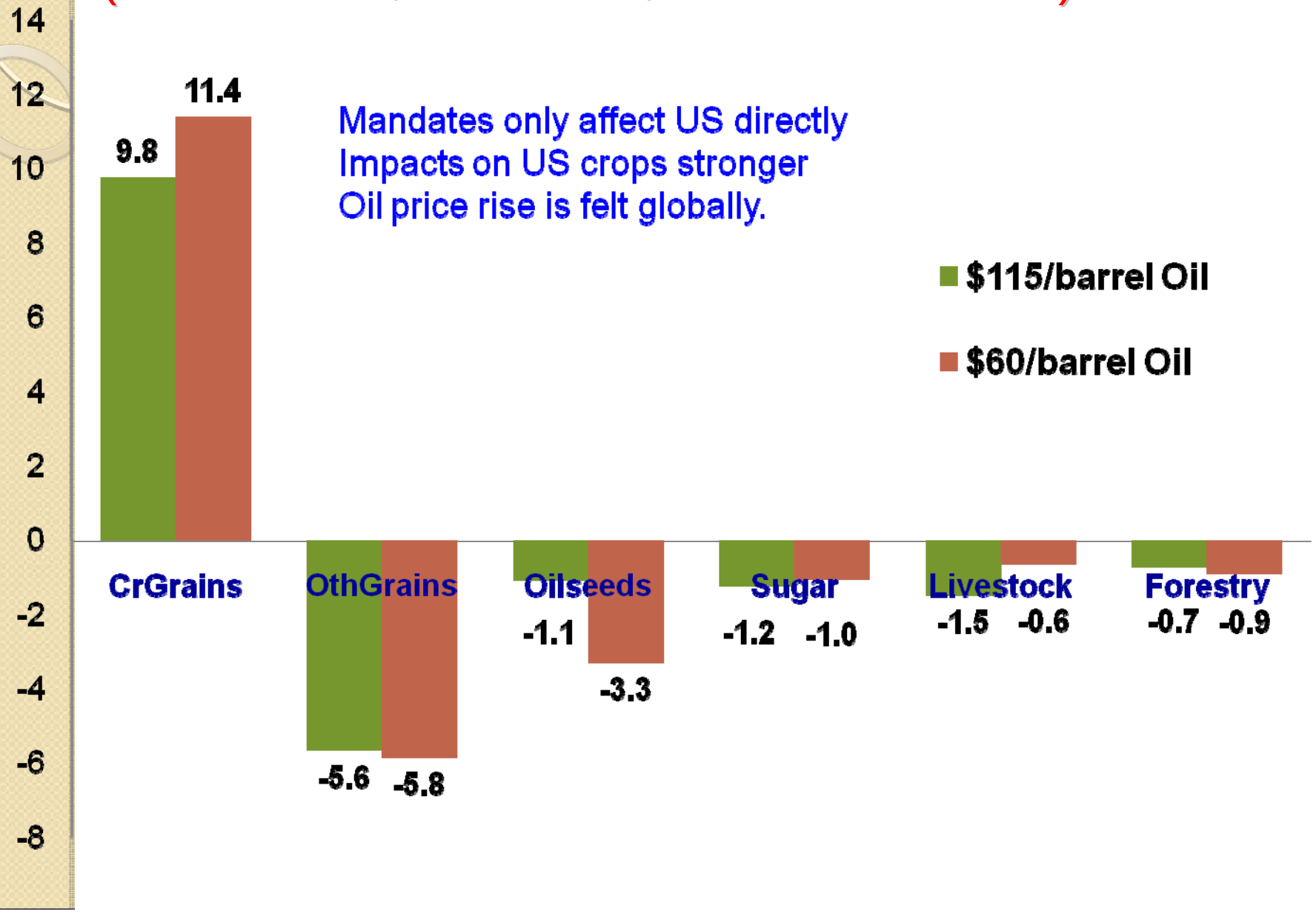
US Coarse grains sales (%): $115 oil, redundant mandates in 2015



% Change in US land-based production: 2006-2015
(impact of $115 oil, mandate redundant)

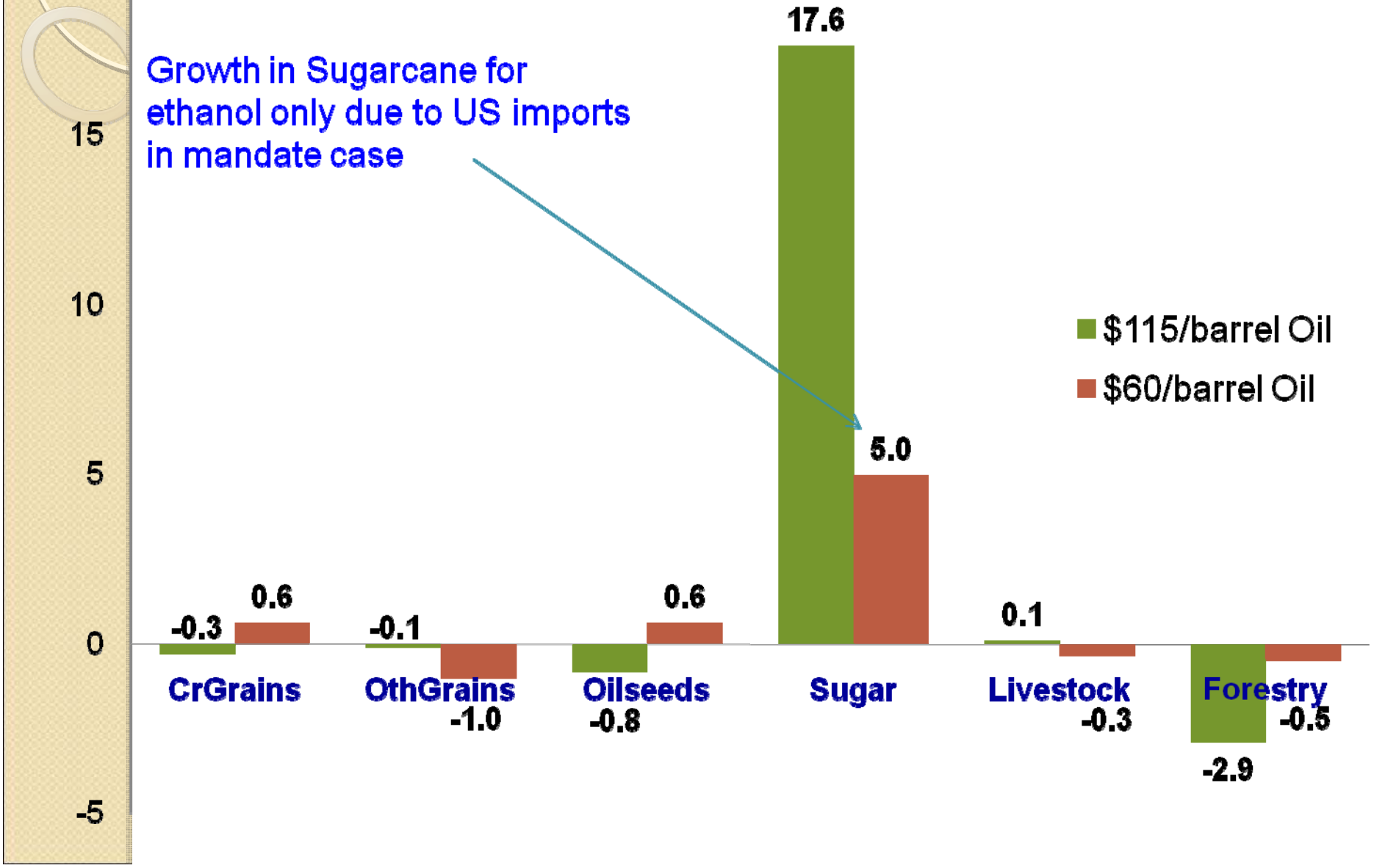


% Change in US land-based production:
(2006–2015: $115 oil vs. $60 oil with US RFS)



% Change in Brazil land-based production:

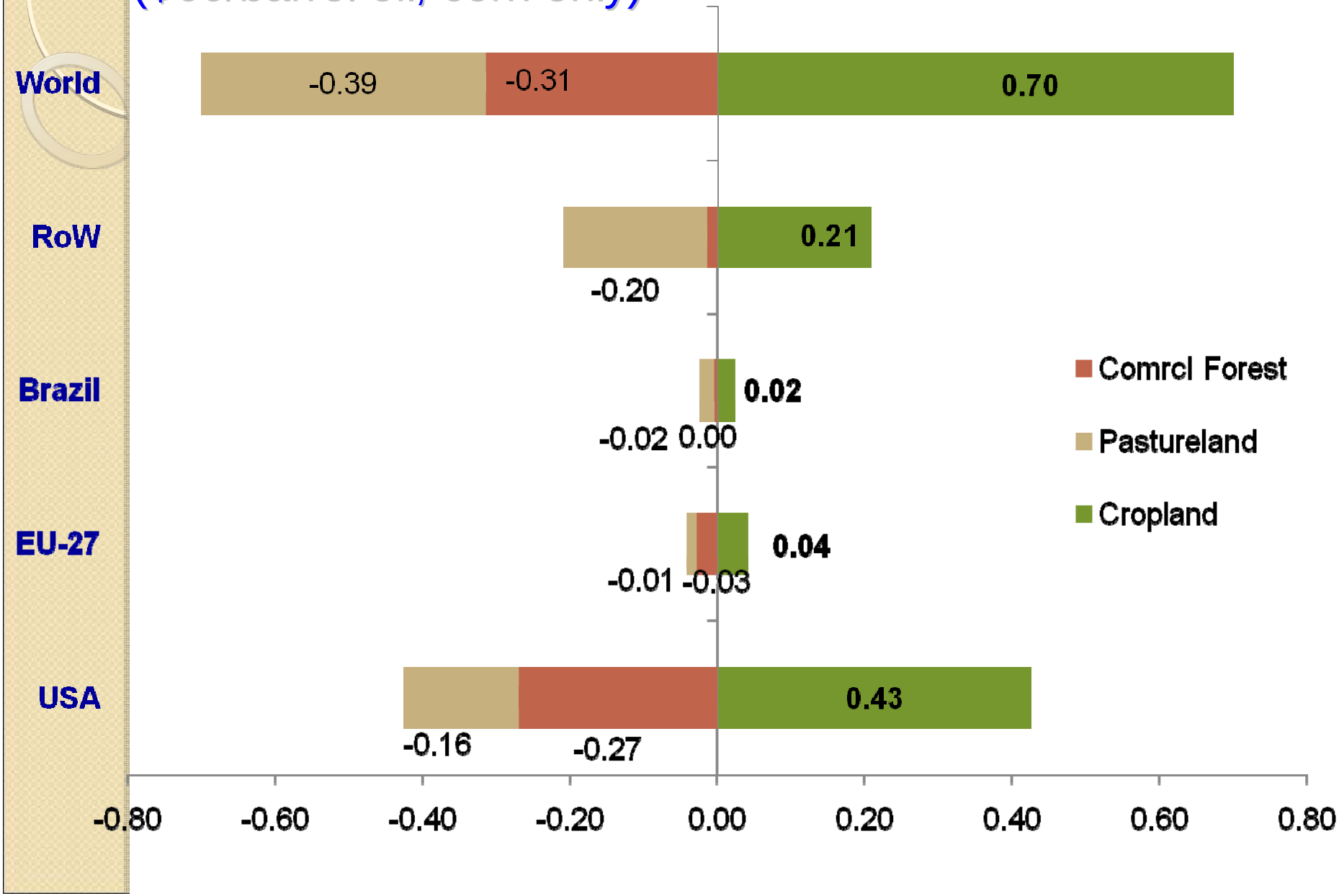
(2006–2015: $115 oil vs. $60 oil with US RFS)



Corn Ethanol Only: 2006-2015 $60 Oil

- Now let us isolate the impacts of corn ethanol, in particular. In this simulation, we only implement the mandate for corn ethanol (15 billion gallons/year by 2015)
- Normalize by 1,000 gallons biofuel and compare to RFS (including imported ethanol and biodiesel)

Land Area Converted (Ha/1000 gallons):
($60/barrel oil, corn only)

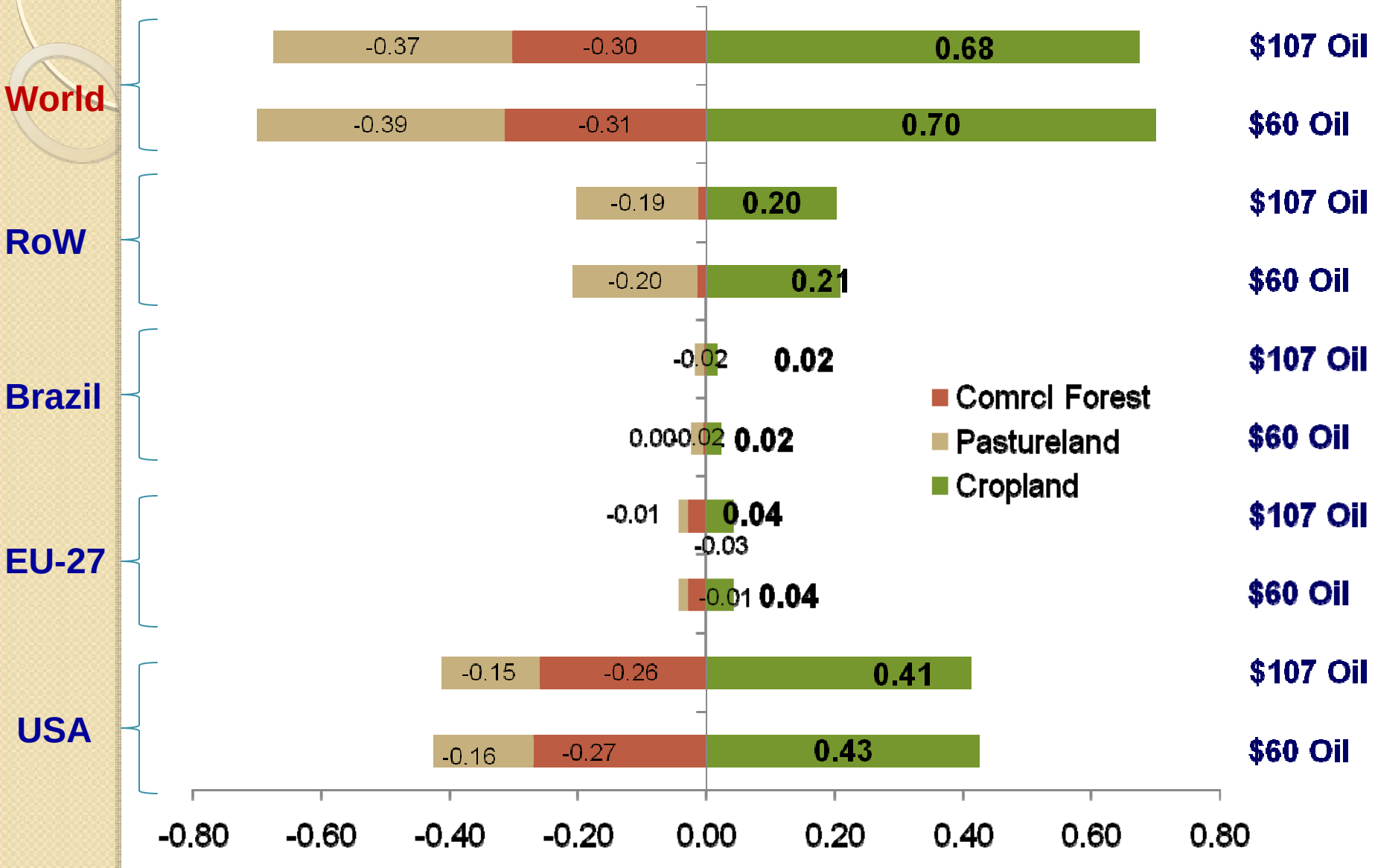


Corn Ethanol Only:
$107 oil, incremental 2 billion gallons in 2015

- What if oil prices settle back to a somewhat lower level – say $107? This leaves us 2 billion gallons short of the 15 bill target in 2015
- Examine impact of a mandate which satisfies the final 2bgy
- Contrast this incremental impact with the previous (larger) corn-only mandate of 10 billion gallons, based on $60 oil

Land Area Converted (Ha/1000 gallons):

($60 vs. $107/barrel oil and US Corn-Ethanol only – **2 bgy** increment)

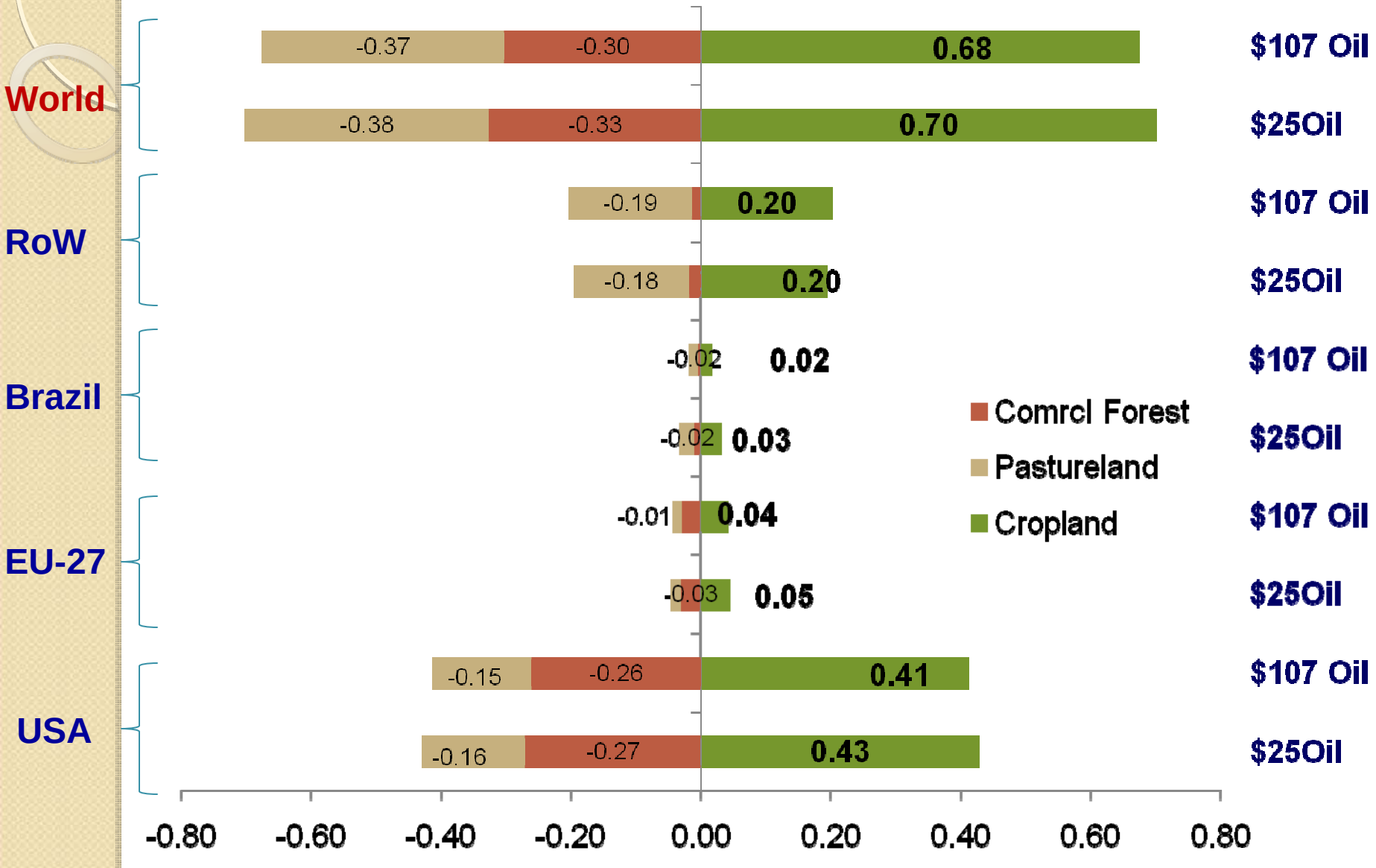


Corn Ethanol Only: 2001-2015 ($25 Oil) (increment of 13.25 billion gallons)

- Finally, consider the impact of going from 2001 production (1.75 bgy at $25 oil) to the 2015 target all in one step
- This is useful as it assesses the impact of the entire corn ethanol industry since 2001
- The 2001 base is useful, as this is the latest year for which global crop land use data are available at the grid-cell level

Land Area Converted (Ha/1000 gallons):

($25 vs. $107/barrel oil and US Corn-Ethanol only – **2 bgy** increment)



Cropland Required (Ha/ 1000 gallons)

	$60 Oil + Corn-Eth only (2006-15)	**$107 Oil + 2 bgy increment** (>2015)	**$25 Oil + Corn-Eth only** (2001-15)
Incremental billion gallons	10.21	1.89	13.25
USA	0.426	0.413	0.429
EU-27	0.042	0.042	0.045
Brazil	0.024	0.017	0.032
Mid East	0.010	0.010	0.013
Oceania	0.011	0.011	0.013
Africa	0.071	0.069	0.061
Canada	0.030	0.028	0.031
Asia	0.008	0.008	0.010
EE-Russia	0.040	0.038	0.030
OthLatAm	0.039	0.039	0.037
World	**0.701**	**0.675**	**0.701**

Conceptual issues in analysis of land use:
(All subsequent discussion based on 2001-2015 corn only)

- **Impacts of expanding ethanol production in the US**

  - more corn required, *bids up price of corn* and corn land

  - intensification of production – *yield increase* on existing acreage

  - displacement of other crops: which ones? Depends on AEZ

  - conversion of pasture/forest to crops: Depends on competing land cover within AEZ

  - How much do yields fall off as expand corn/crop acreage?

- **Global impacts**

  - increased US demand reduces US exports, increases imports from rest of world of crops, livestock products and biofuels;

  - where increased production occurs *depends on pattern of trade*

  - increased global yields for crops in response to higher prices

  - acreage response as well, with increased cropland drawn from other land cover types

Impacts on US Coarse Grains Output

US corn only mandates: 2001-2015		
US farm-2001	**National**	**AEZ10 – "Corn belt"**
Yield (ch 2001-2015)	**135 bushels/acre** (+3bu/ac) (+3%)	**151 bushels/acre** (+2.3bu/ac) (+1.5%)
Area (ch 2001-2015)	**90 mill acres** (+14 m.ac) (+15%)	**38 mill acres** (+5m.ac) (+14%)
Production (ch 2001-2015)	**12157 mill bushels** (+2133 m.bu) (+18%)	**5718 mill bushels** (+883 m.bu) (15.5%)
Yield Intensification (increased inputs)		4.7 %
Yield Extensification (marginal lands)		-2.6 %
Total Yield Effect		**1.5 %**

Which crops will be displaced? Depends on Agro-Ecological Zone (AEZ)

- Begin with 0.5 degree grid cell global land use data base:

  - Obtain crop land cover from satellite data, but distinguishing crop type requires on-the-ground data

  - AgroMaps = joint project between FAO, IFPRI and SAGE to map the world's crop production; combine satellite data with county level harvested area and production data

  - Monfreda et al. have made this into a usable data set circa 2001

- Aggregate grid cells to AEZs based on common LGP:

  - Length of Growing Period (LGP) depends on temperature and moisture availability

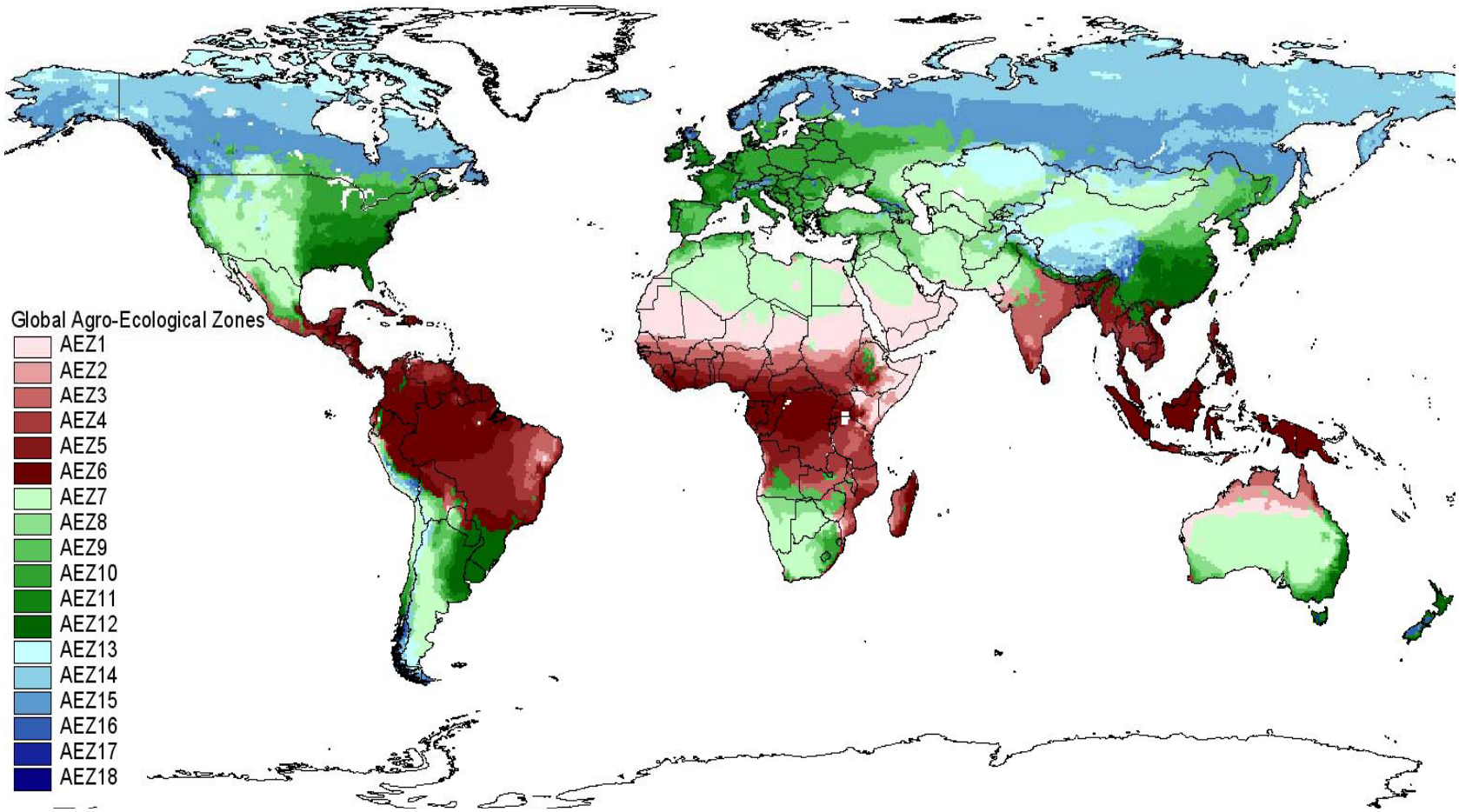
  - 18 AEZs = 6 LGPs x 3 climate zones

  - Resulting AEZs not necessarily contiguous

  - Use AEZs to disaggregate land endowment in model

  - Crops compete within AEZ for common land base; if crop is not present, will not compete

Global Distribution of AEZs

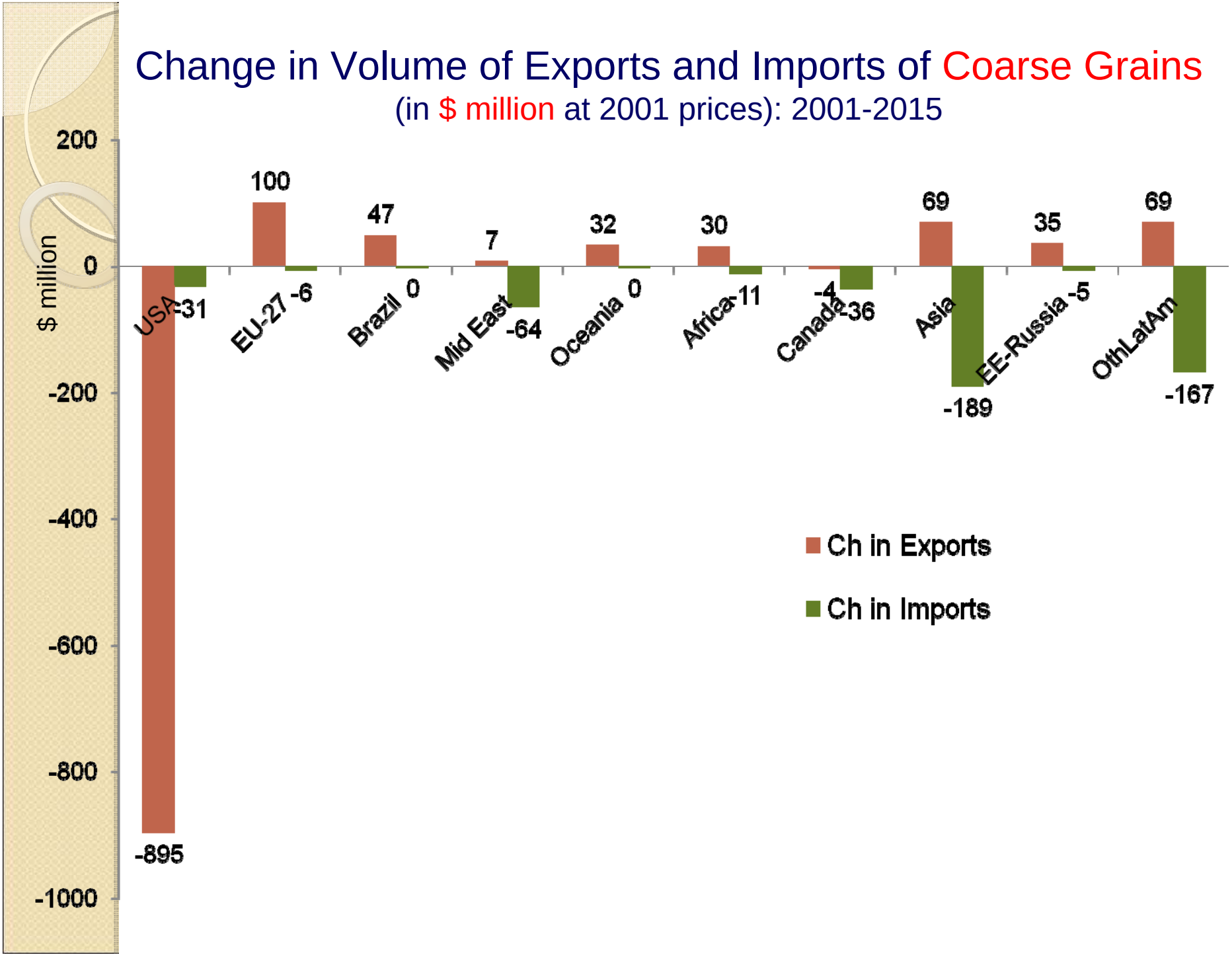


Where in RoW will production respond?

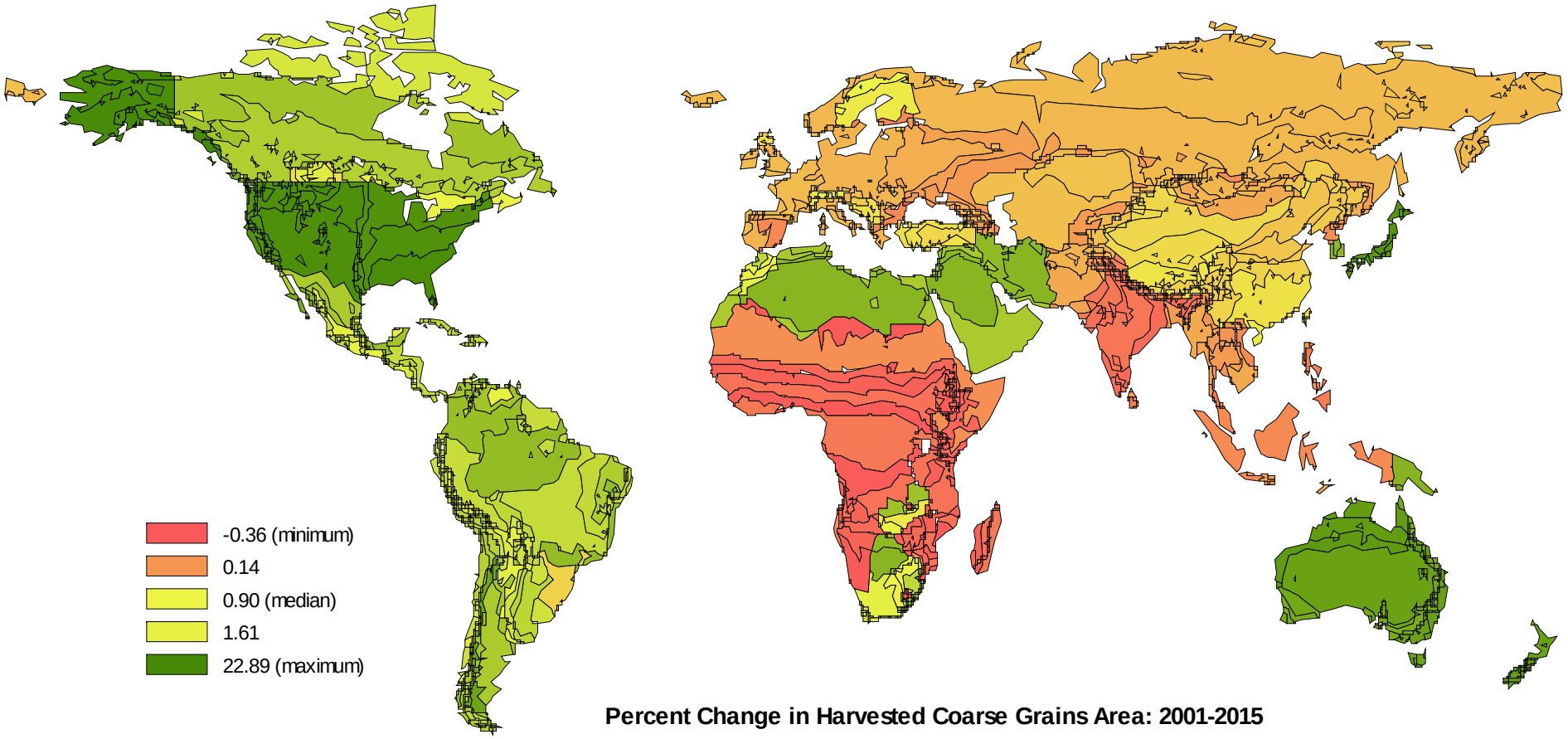
- Reduction in US exports will be largely offset by competitors; also a modest increase in US imports
- Trade patterns show rigidity, but do respond to relative price changes: bilateral trade elasticities are key:
  - we don't expect Japan to completely change import sourcing from US when prices rise by $1, however, import sourcing is sensitive to prices
  - we expect the global impacts to depend on the country initiating the biofuels program: Geography matters!

Change in Volume of Exports and Imports of Coarse Grains

(in $ million at 2001 prices): 2001-2015



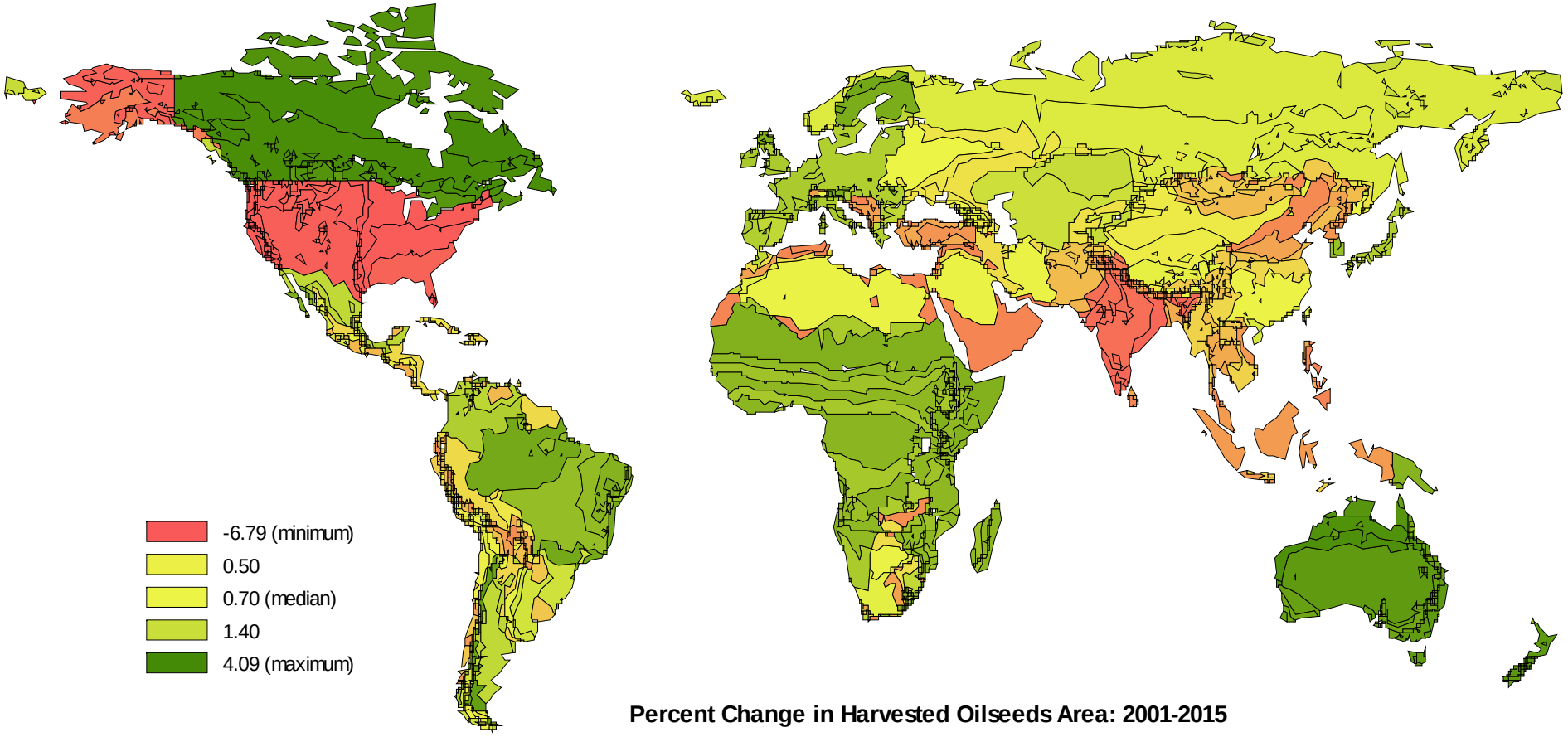
Change in Harvested Coarse Grains Area



Percent Change in Harvested Coarse Grains Area: 2001-2015

Coarse Grains(13.25 bgy)	USA	Canada	EU	Brazil
Percent change	15.08	1.10	0.19	1.06

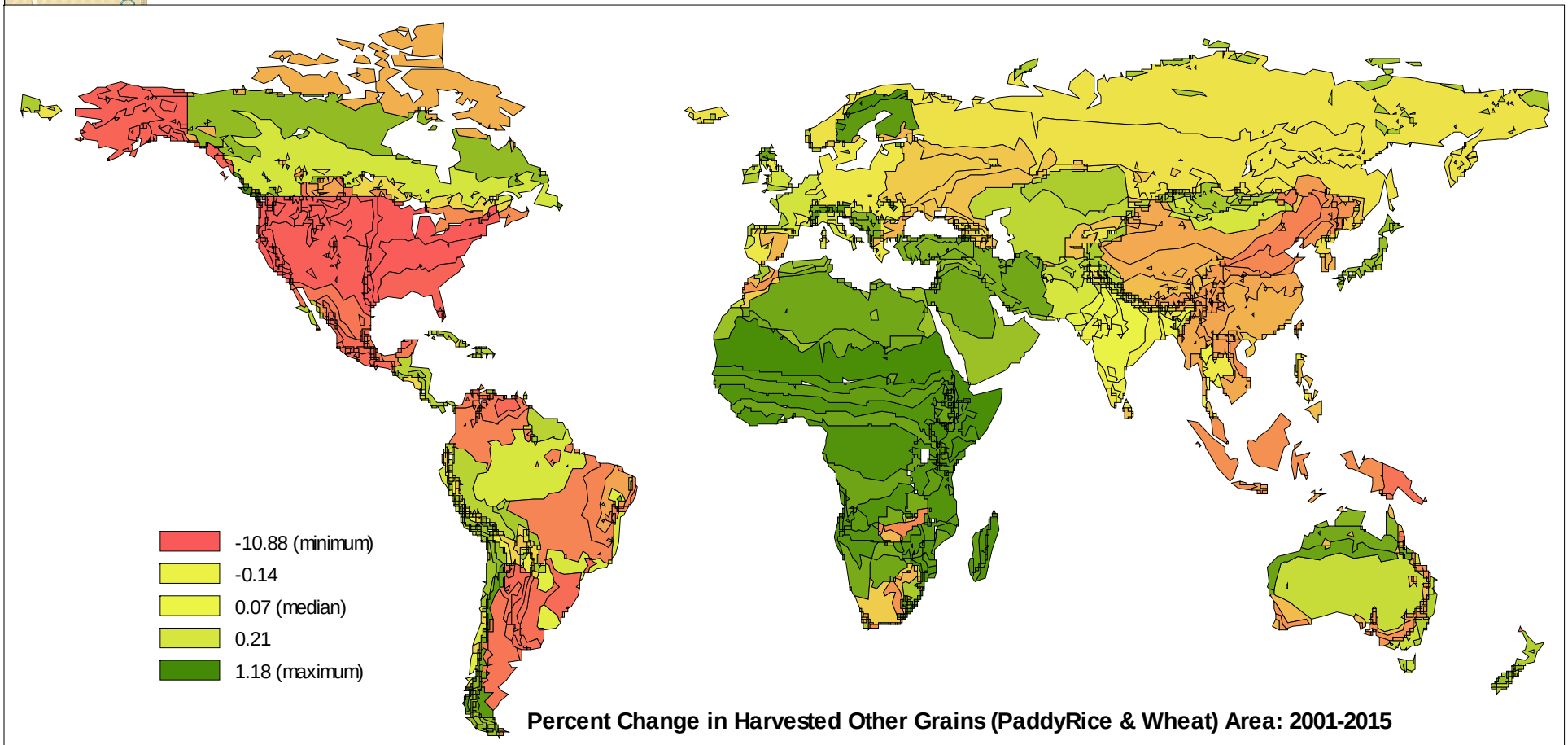
Change in Harvested Oilseeds Area



Percent Change in Harvested Oilseeds Area: 2001-2015

Oilseeds: (13.25 bgy)	USA	Canada	EU	Brazil
Percent change	-5.37	2.76	1.17	1.25

Change in Harvested Other Grains Area

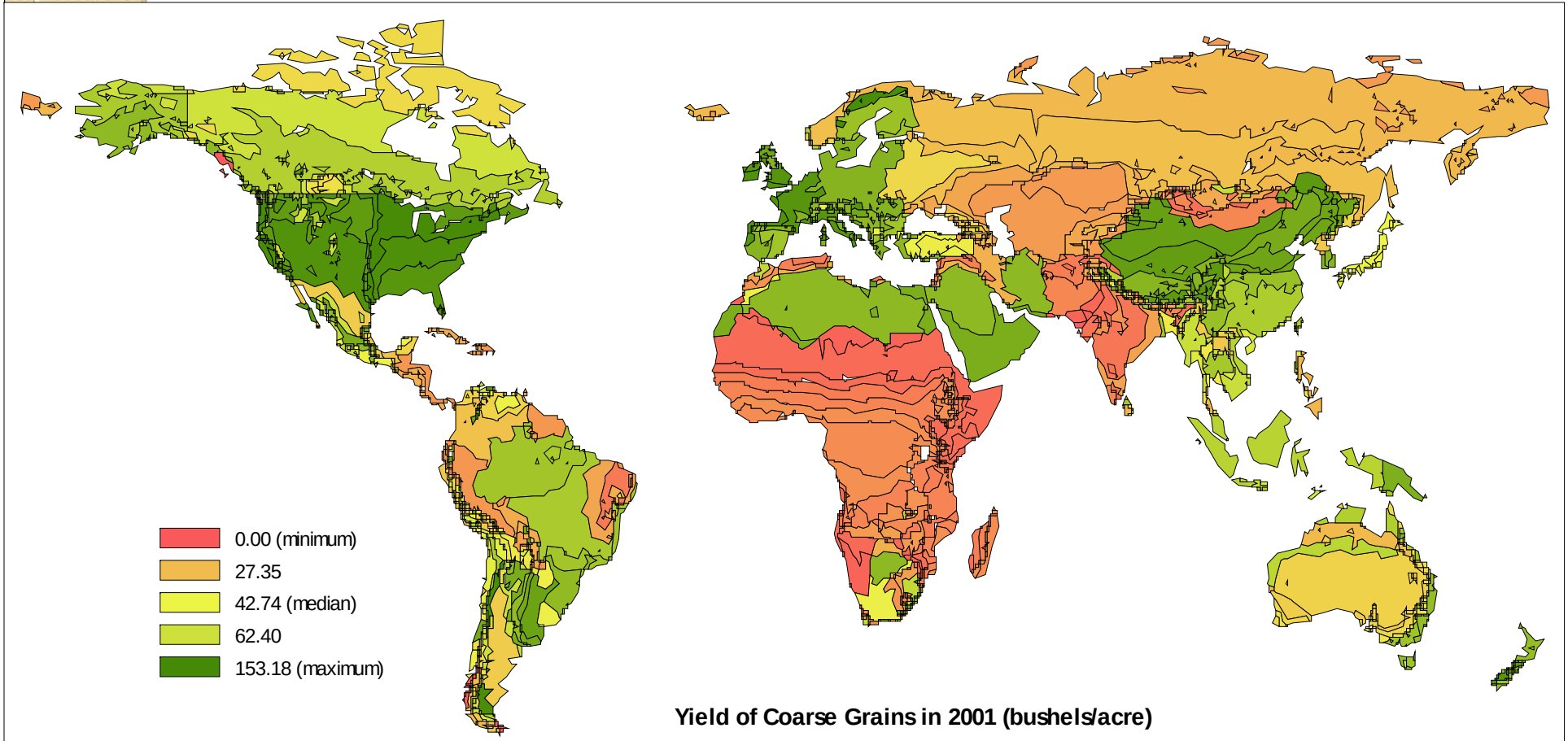


Percent Change in Harvested Other Grains (PaddyRice & Wheat) Area: 2001-2015

Other Grains: (13.25 bgy)	USA	Canada	EU	Brazil
Percent change	-9.21	-0.08	0.08	-0.27

Physical Yield of Coarse Grains in 2001

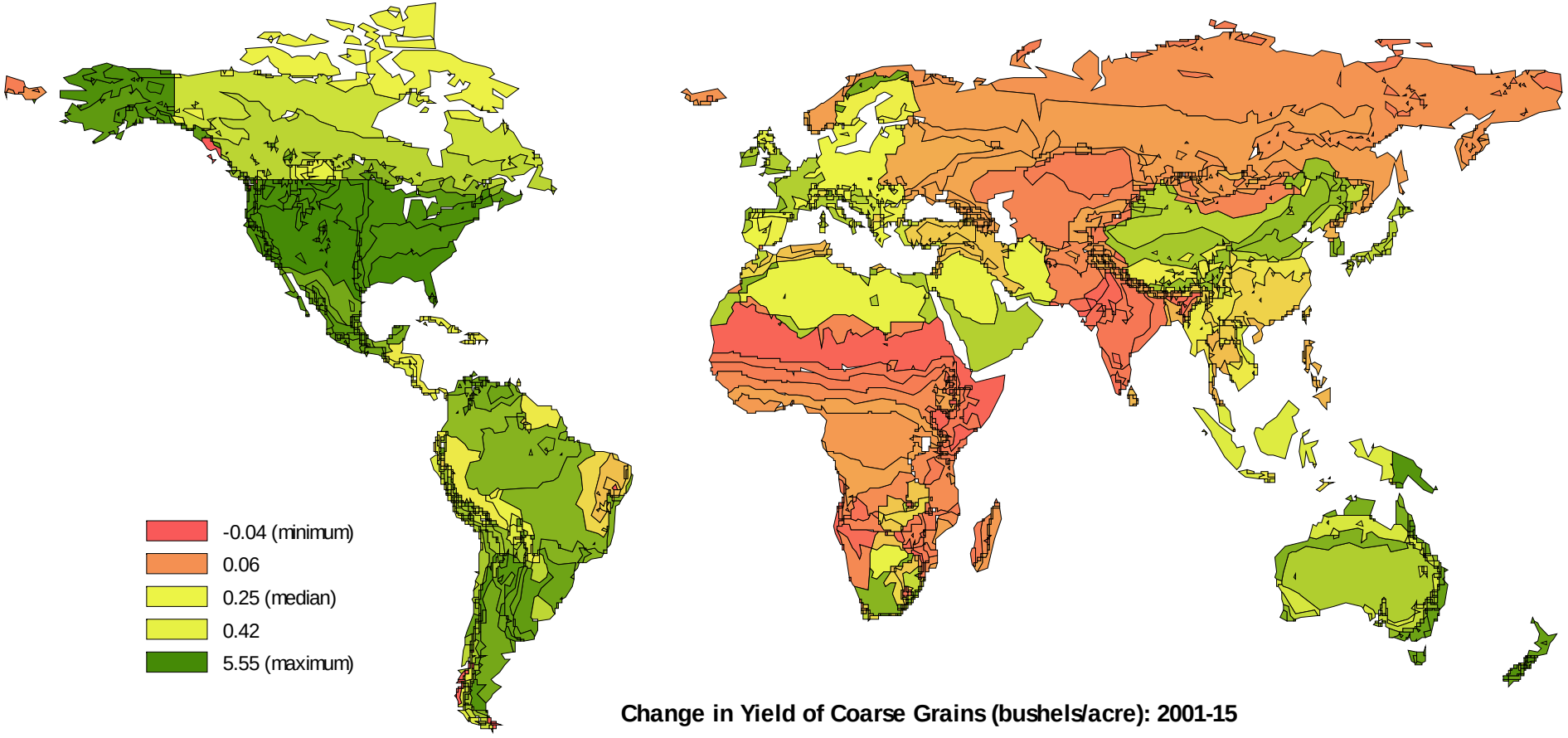
(bushels/acre)



Yield of Coarse Grains in 2001 (bushels/acre)

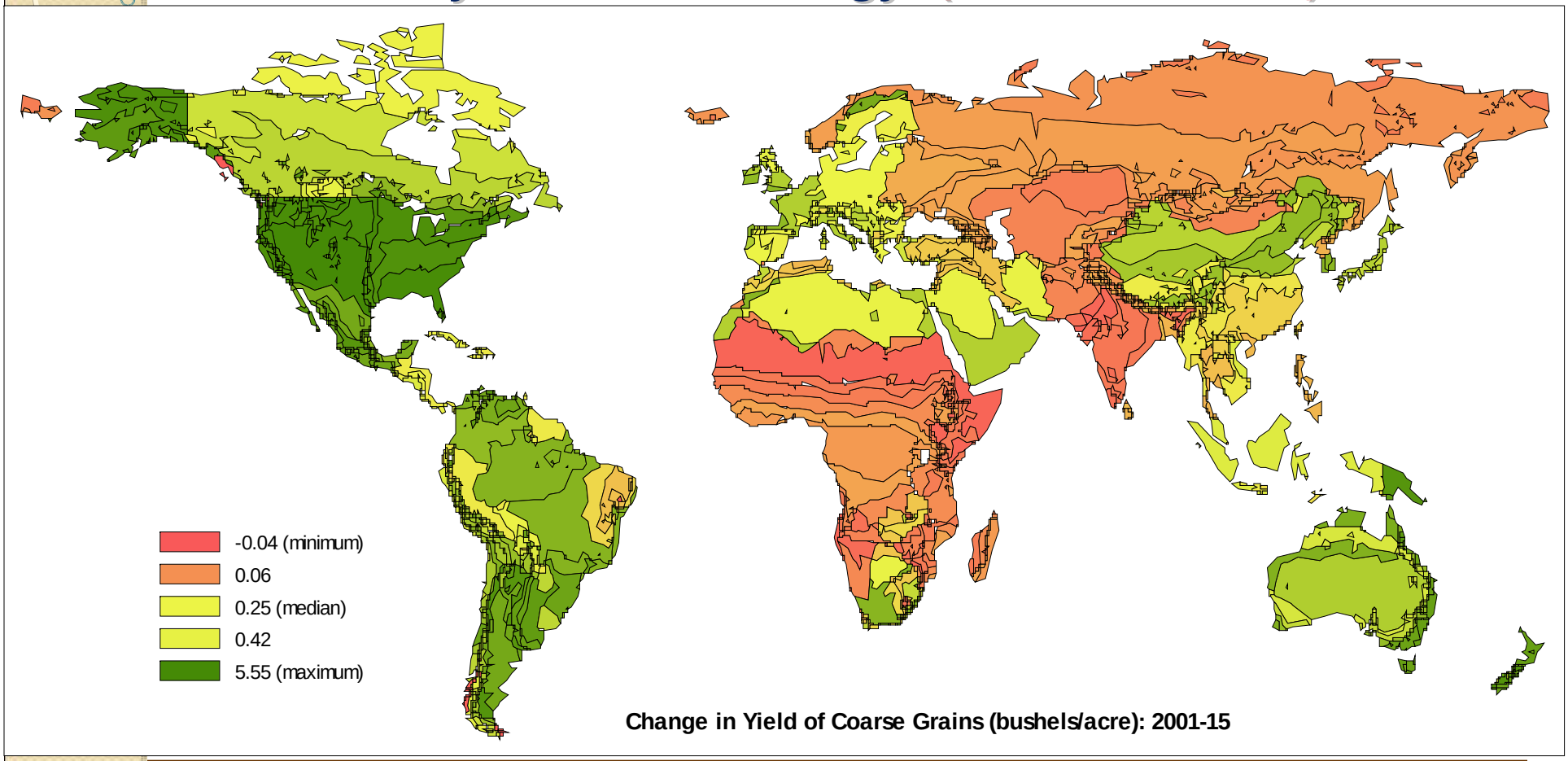
Coarse Grains	USA – AEZ10	Canada – AEZ10	EU – AEZ14	Brazil – AEZ12
Yield (bushels/acre)	151	107	149	65

Change in Coarse Grains Yield : Corn ethanol only, 1.75 to 15 bgy (bushels/acre)



Cr Grains: (13.25 bgy)	USA – AEZ10	Canada – AEZ10	EU – AEZ14	Brazil – AEZ12
Change in Yield (bushels/acre)	+2.3	+0.9	+0.5	+0.7

Change in Coarse Grains Production: Corn ethanol only, 1.75 to 15 bgy (million bushels)



Coarse Grains: (2001-15)	USA	Canada	EU	Brazil
Change in Production (mill. bushels)	2134	21	37	31

Change in Crop Harvested Area: 2001-2015

(**million acres**; worldwide total additional area = 5.37)

	Coarse Grains	Oilseeds	Sugar-crops	Other Grains	Other Agri	**Total**
USA	13.70	-4.37	-0.08	-6.67	-0.50	2.07
EU-27	0.16	0.38	-0.01	0.05	0.00	0.57
Brazil	0.32	0.44	-0.15	-0.02	-0.21	0.39
Mid East	0.24	0.02	-0.003	0.03	-0.20	0.09
Oceania	0.23	0.06	-0.004	-0.04	-0.11	0.14
Africa	0.03	0.59	-0.004	0.13	0.05	0.80
Canada	0.21	0.48	0.000	-0.02	-0.07	0.60
Asia	0.39	0.63	-0.04	-0.01	-0.87	0.10
EE-Russia	0.24	0.16	-0.01	0.01	-0.12	0.30
Oth Lat Am	0.62	0.30	-0.08	-0.13	-0.41	0.30
World Total	**16.14**	**-1.31**	**-0.37**	**-6.65**	**-2.43**	**5.37**

Where does the additional crop land come from? Predicting changes in land cover and productivity

- Increased profitability of crops expected to lead to conversion of some land from pasture and forestry
- Wide range of estimates of elasticity of supply of land cover to crops; we use Lubowski et al. based on NRI data points: 1982-1997; additional crop land expected to come from all cover types
- Even tougher issue is that of predicting productivity of converted lands in crops: how much will crop yields fall as move onto more marginal lands? If they fall a lot, then need more land to replace the same amount of diverted food production.

Predicting changes in land cover and productivity

- Use land rents as a predictor of productivity: common unit ($/acre) which measures economic contribution of land under actual production circumstances
- US cash rents show significant differences in productivity across land cover types (e.g., for 2007)

  - Overall US average = $85 per acre of crop land

  - But only $12 per acre of pasture

  - Take this as an estimate of the average productivity differential

  - But land moving into crops is likely to be the more productive grazing land (e.g., Lubowski); use model to compute adjustment to average productivity of pasture, forest and crop land within the AEZ which reconciles economic and physical constraints

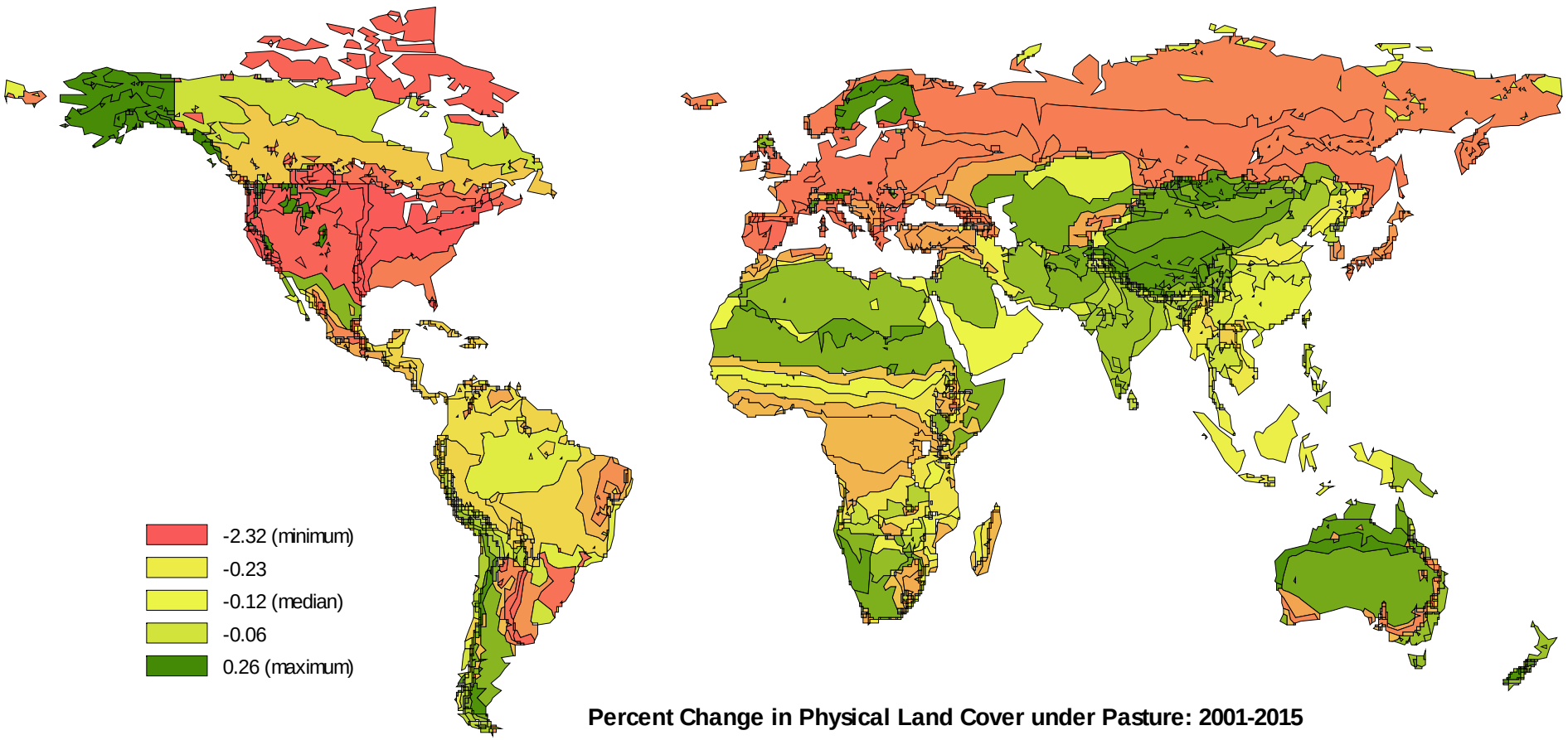
An Illustration: AEZ12/USA (2001-2015)

cover type	Rents (US $ per acre)	*percentage change*		Physical land
		Effective land	Productivity Adjust	
Forestry	28	-1.7	-1.11	-0.59
Grazing	8	-1.43	-1.11	-0.32
Cropland	78	1.31	-1.11	2.42

Discussion: As move the best grazing land into crops, average grazing yields fall, so effective land falls more than physical hectares.

On the other hand, as grazing land is converted to crop land, the average productivity of crop land falls, as this land has much lower land rents, so effective land rises less than physical cropland.

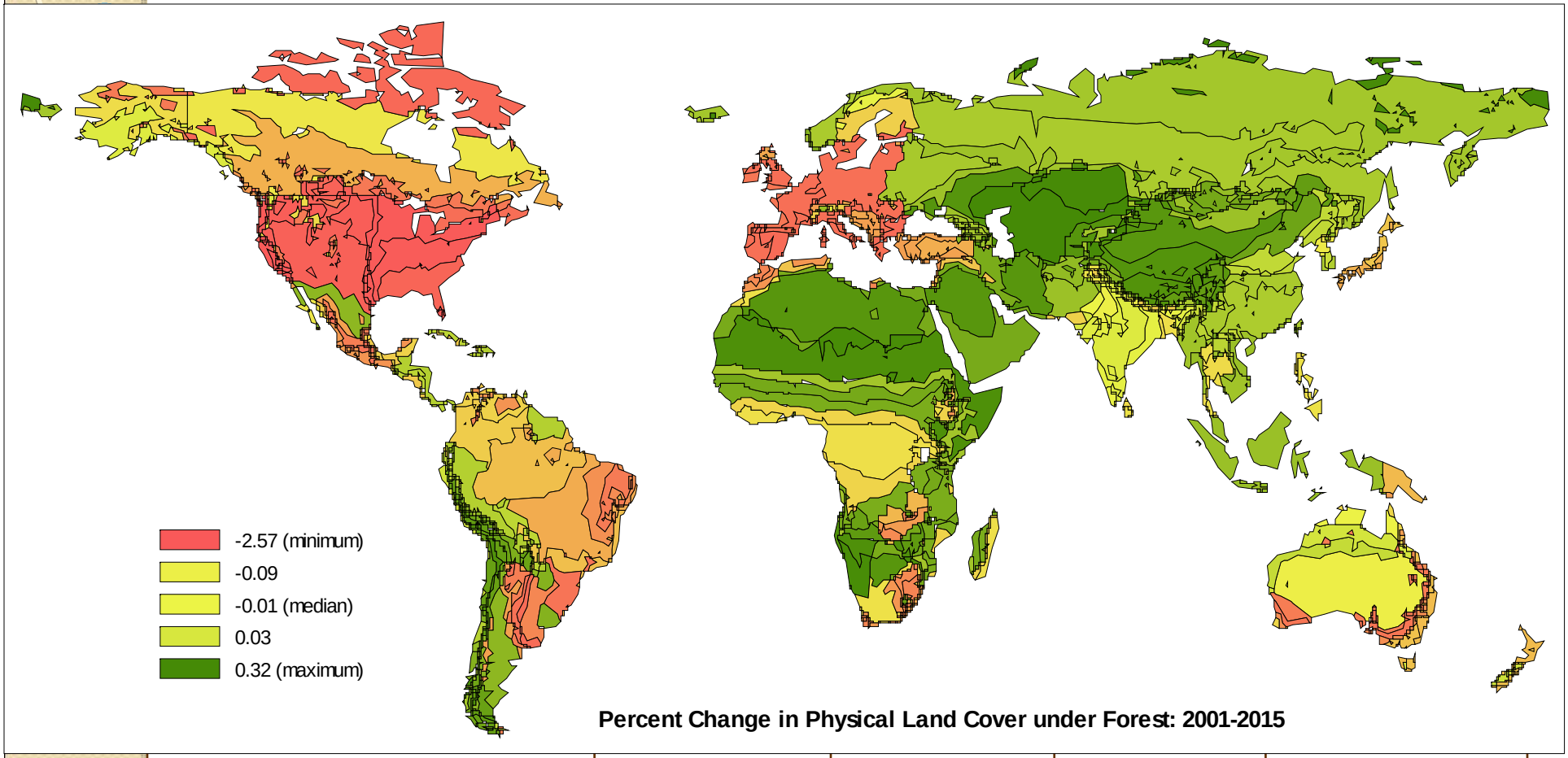
Change in Physical Land Cover under Pasture



Percent Change in Physical Land Cover under Pasture: 2001-2015

Pasture: (2001-15)	USA	Canada	EU	Brazil
Percent change	-0.91	-0.54	-0.33	-0.17

Change in Physical Land Cover under Forest



Percent Change in Physical Land Cover under Forest: 2001-2015

Forest: (2001-15)	USA	Canada	EU	Brazil
Percent change	-1.06	-0.09	-0.27	-0.07

Change in Physical Land Cover : 2001-2015

(million acres)

	Pasture land	Commercial Forest
USA	-5.27	-8.93
EU-27	-0.53	-0.97
Brazil	-0.78	-0.28
Mid East	-0.42	0.00
Oceania	-0.38	-0.05
Africa	-1.96	-0.07
Canada	-0.28	-0.76
Asia	-0.44	0.11
EE-Russia	-1.31	0.31
Oth Lat Am	-1.09	-0.15
World	**-12.45**	**-10.78**

Need **23 million marginal acres** to boost average crop land equivalent by **5.4 million acres**

How robust are these results?

- Employ Systematic Sensitivity Analysis to evaluate robustness
- Specify distributions for key parameters:
  - Yield elasticities
  - Crop acreage response
  - Land cover elasticities
  - Trade elasticities
- Sample from these distributions and solve the model many times
- Produce mean and standard deviation for land cover changes
- Construct 95% confidence intervals (assuming normality)

Sensitivity of Crop Cover Change to Key Parameters: 2001-2015

	Crop Cover change (%)	95% Confidence Interval	
		Lower	Upper
USA	0.63	0.35	0.91
EU-27	0.19	0.06	0.32
Brazil	0.31	0.11	0.51
Mid East	0.12	0.03	0.21
Oceania	0.22	0.06	0.37
Africa	0.53	0.20	0.87
Canada	0.70	0.30	1.09
Asia	0.14	-0.03	0.30
EE-Russia	0.21	0.06	0.36
Oth Lat Am	0.31	0.10	0.51

Conclusions: Impact of expanded biofuel production

- Impacts depend in part on source of expansion:
  - Oil prices (market driven)
  - Mandate driven/depends on profile of mandates by type of biofuel (corn only vs. sugarcane ethanol)
- Once focus on corn-ethanol only, and normalize for the size of the shock, land cover results are fairly robust across scenarios: e.g., 0.70 ha./1000 gallons of mandate
- About half of cropland conversion in US, half overseas
- Land cover changes are uncertain, but, with the exception of Asia, sign of change is robust

Qualifications

- CAUTION! Results are preliminary
- We are more confident in changes in crop output, trade and harvested area; less confident of changes in land cover
- Working to reconcile enormous differences in land rents with economic rationality:
  - Land conversion costs
  - Heterogeneity within AEZs
- Have wholly ignored unmanaged land/inaccessible forest: How costly to access? How productive?

Thanks very much!

Questions and Comments

For more information:
www.gtap.agecon.purdue.edu/resources/working_papers.asp