The Role of Irrigation in Determining the Global Land Use Impacts of Biofuels

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Outline

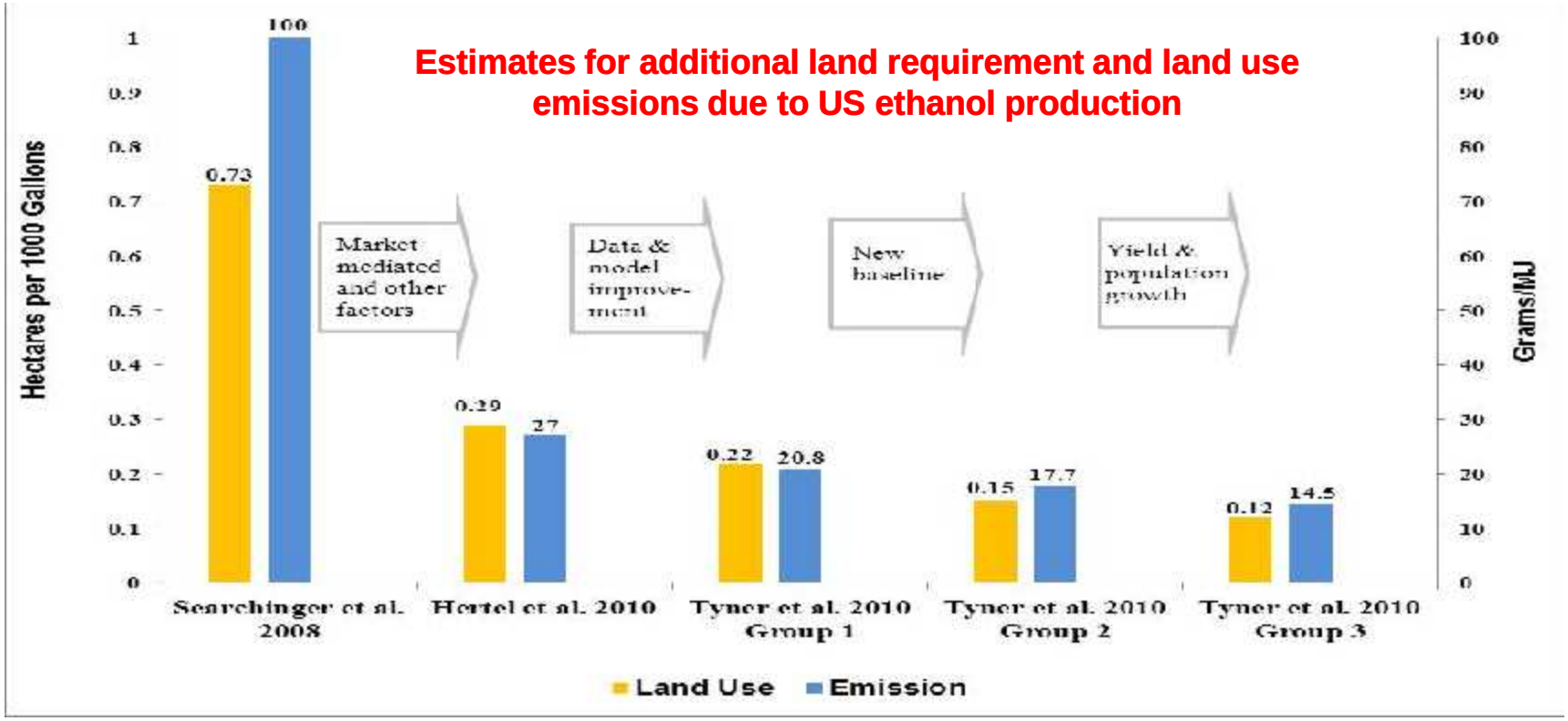
- Literature review and background,
- Research motivation,
- Steps in our analysis,
- Role of irrigation in agriculture,
- Modifications in GTAP data base,
- Modifications in GTAP-BIO model,
- Scenarios,
- Land use changes,
- Emissions,
- Conclusions.

Literature review and background (1)

- **Prior to 2007, the general consensus was that corn ethanol can reduce GHGs a bit more than 20% after considering all the direct effects.**
- **However, analysis ignored indirect land use impacts.**
- **By the second half of 2007, the importance of indirect land use change induced emissions was circulating among professionals.**

Literature review and background (2)

- **Several studies have examined land use consequences of biofuel:**
  - **Searchinger, et al., 2008; Hertel et al., 2010, Taheripour et al., 2010, and Tyner et al. 2010.**



Literature review and background (3)

- **Estimates have been picked apart, critiqued and improved in several directions including:**
  - **PE to GE models;**
  - **Uses of biofuel by-products as animal feed;**
  - **Extensive margin.**
- **However, all of these studies have effectively treated all cropland as being rainfed.**
- **The role of irrigation in biofuel-induced cropland expansion has been wholly ignored.**

Research motivation (1)

- **Irrigated croplands typically have much higher yields than their rainfed counterparts in the same Agro Ecological Zone (AEZ).**
- **If the new lands are irrigated, and therefore have higher yields than rainfed lands in the same AEZ, then less land conversion will be required.**
- **If expansion of irrigation is constrained anywhere in the world, it is likely that more cropland area will be required to meet the additional global demand induced by biofuel production.**

Research motivation (2)

- **Omitting explicit analysis of irrigation, and associated constraints, is likely to shift the distribution of land use changes towards dry regions with lower land use emission factors (less above-ground carbon).**
- **In the presence of irrigation constraints the distribution of land use changes induced by biofuel production will shift towards areas where expansion of rainfed agriculture is possible.**
- **These regions may have different emissions factors – will influence global land-based emissions.**

Research motivation (3)

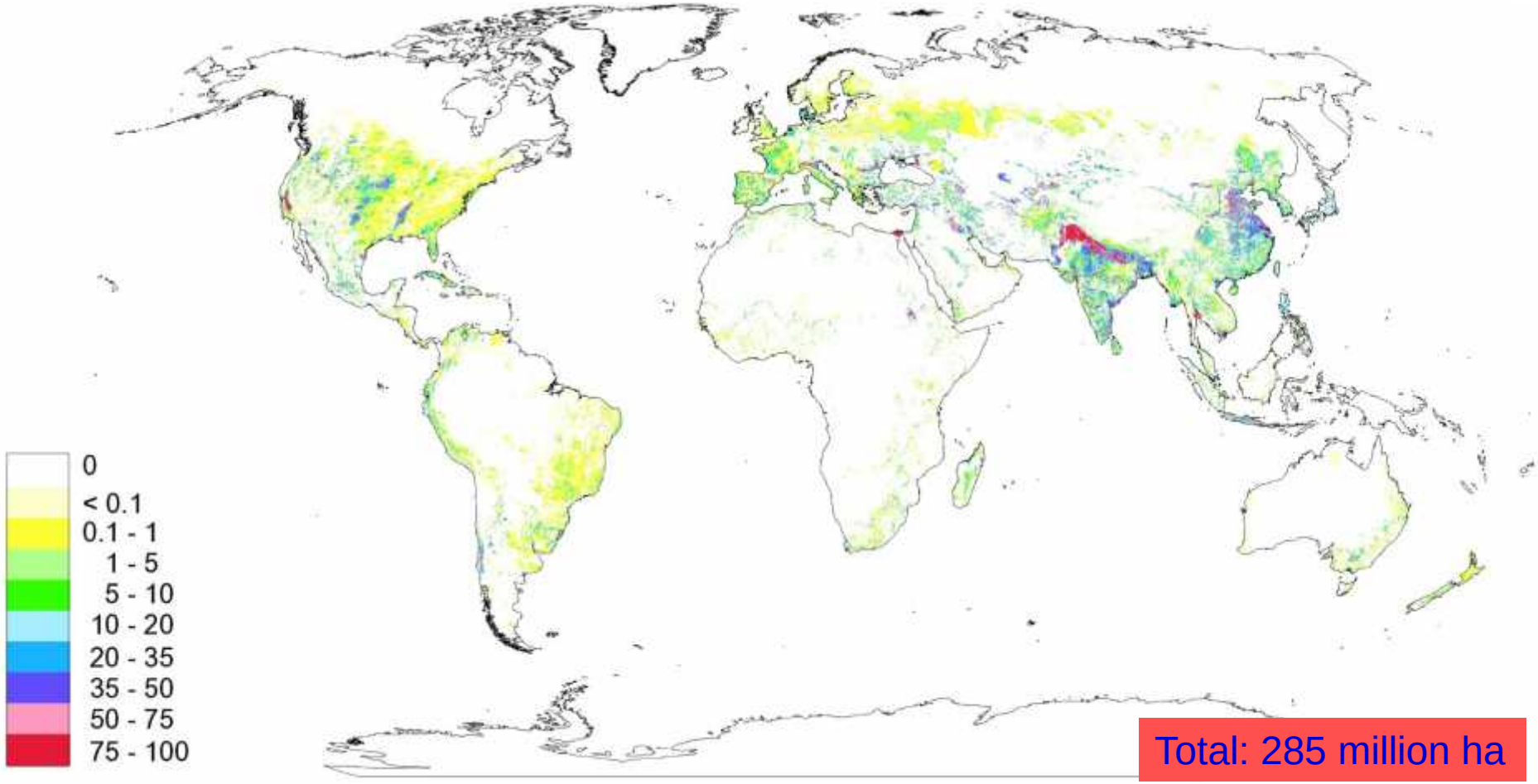
- Earlier studies have co-mingled irrigated and rainfed cropland, so expansion of given crop is effectively an expansion of the average; no irrigation constraint.
- This research explores the land use impacts of US biofuel mandates while distinguishing cropping activities by irrigation type.
- We consider the case in which irrigated and rainfed areas compete; either can expand or contract.
- Then consider the impacts of constraining irrigation.
- Finally restrict model to mimic previous studies.

Steps in our analysis

- **We begin by modifying the GTAP data base to distinguish irrigated and rainfed agriculture based on the pioneering work of Portmann, Siebert, and Döll (2010) – PSD.**
- **In the second step, the GTAP-BIO-AEZ model used in Taheripour, Hertel, and Tyner (2011) is extended and modified to handle production, consumption, and trade of both irrigated and rainfed crops.**
- **Explore impacts of relaxing and constraining irrigation expansion in the face of increased US ethanol production.**

Role of irrigation in agriculture (1)

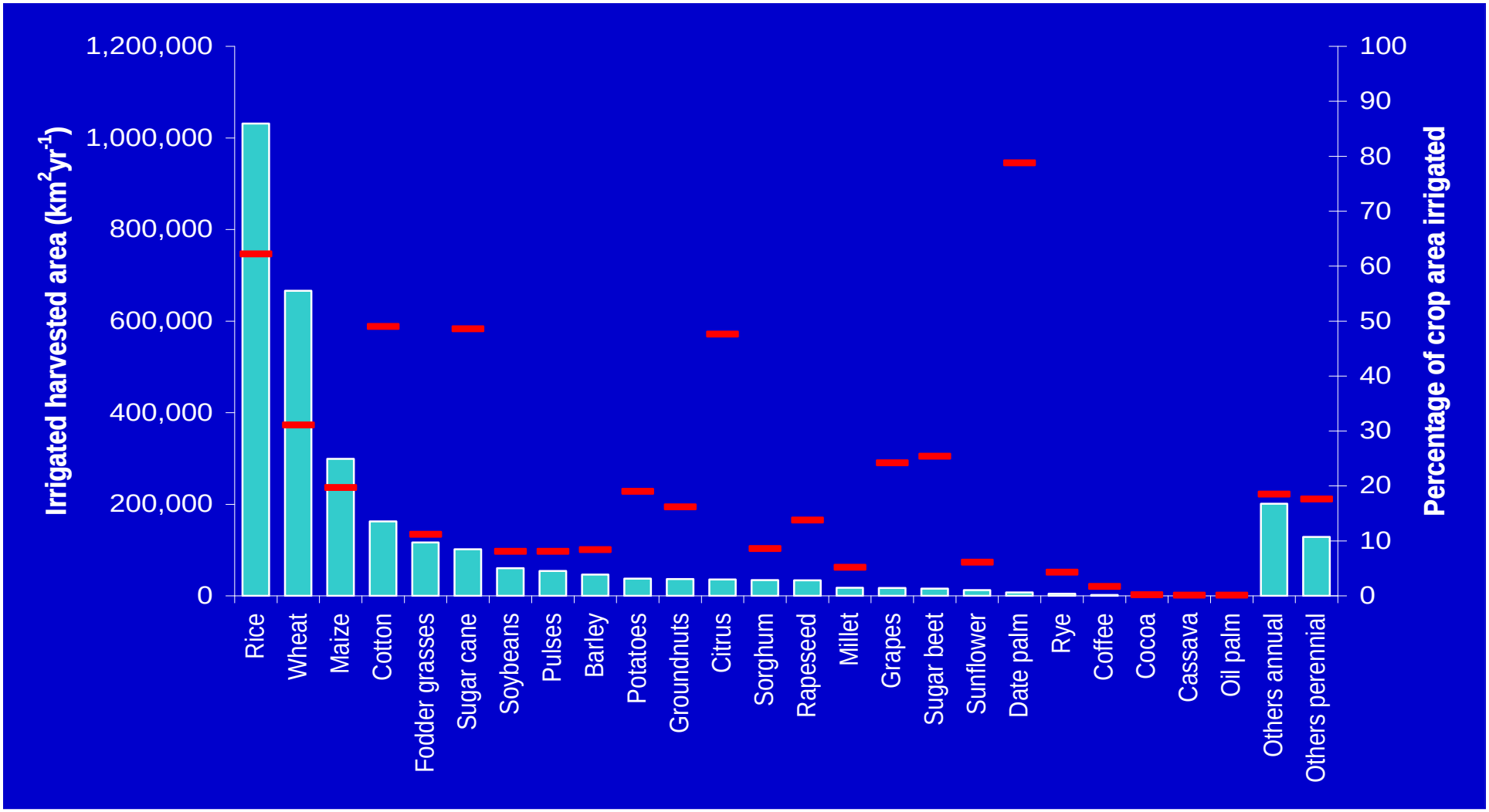
Irrigated area in 2000



Source: Siebert et al., 2006

Role of irrigation in agriculture (2)

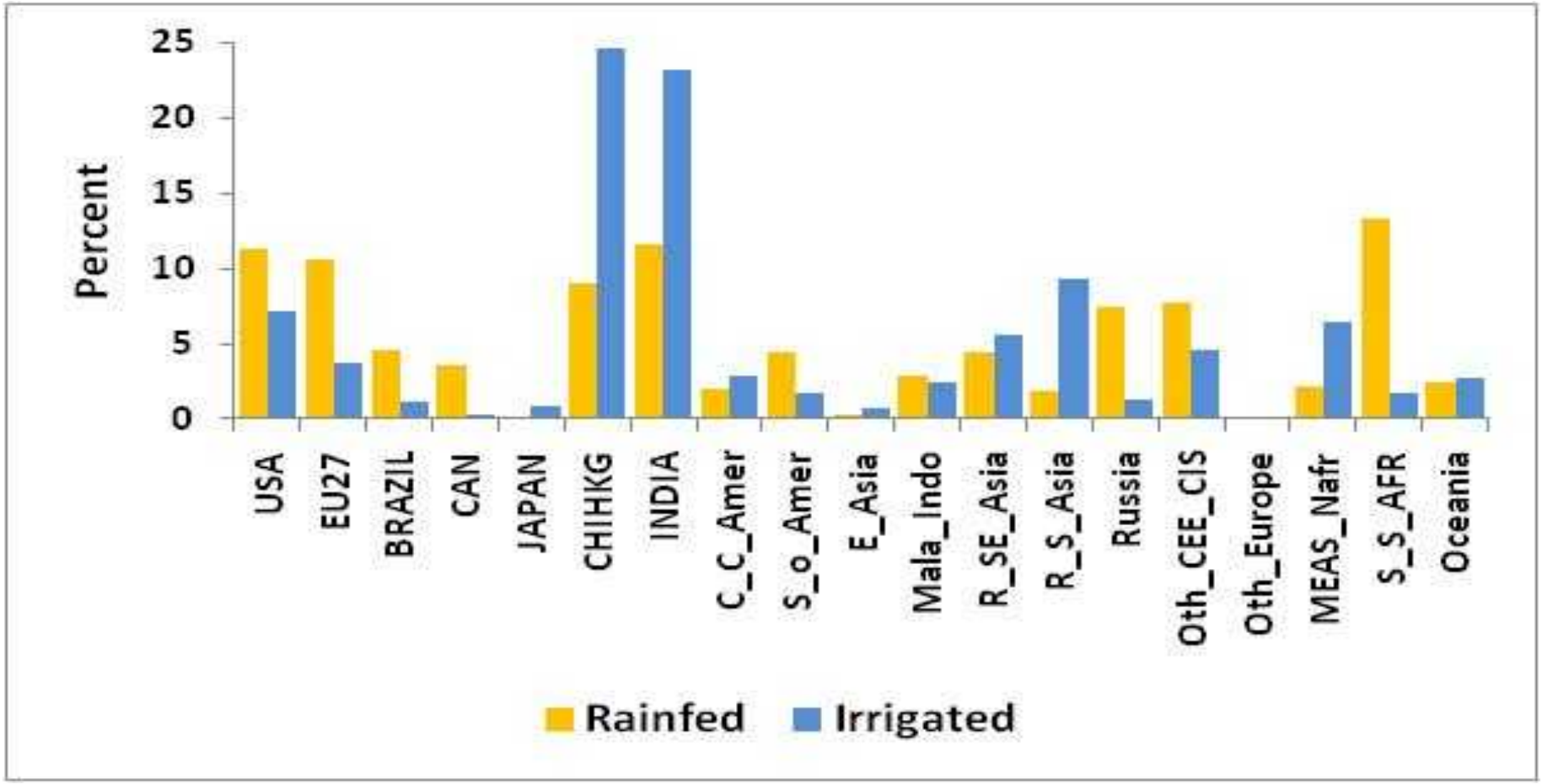
Harvested area of irrigated crops



Source: MIRCA 2000, and Portmann, Siebert, and Döll, 2010

Role of irrigation in agriculture (3)

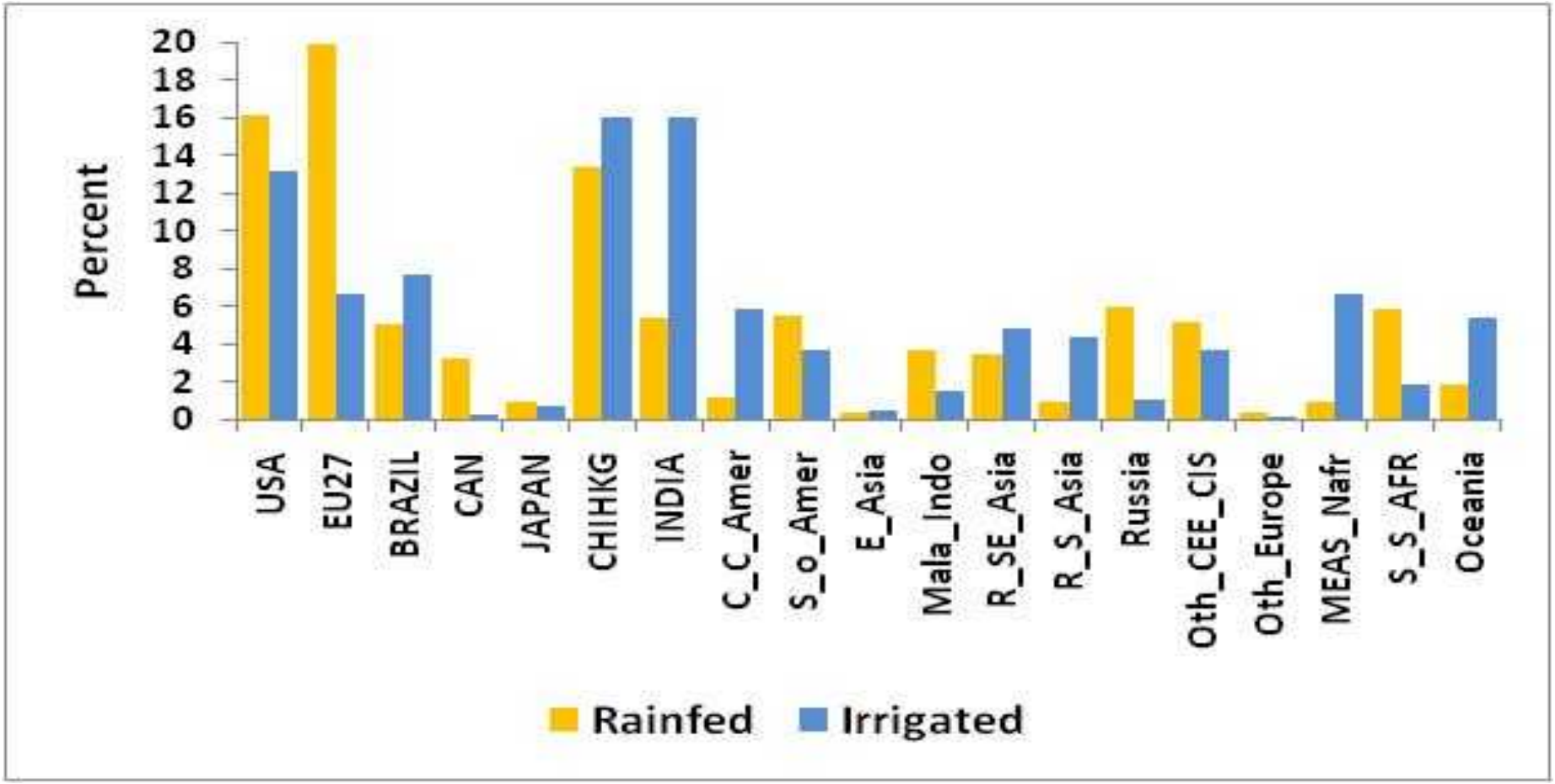
Global distribution of harvested area by irrigation type



Irrigated area accounts for about 20% of global cropland cover

Role of irrigation in agriculture (4)

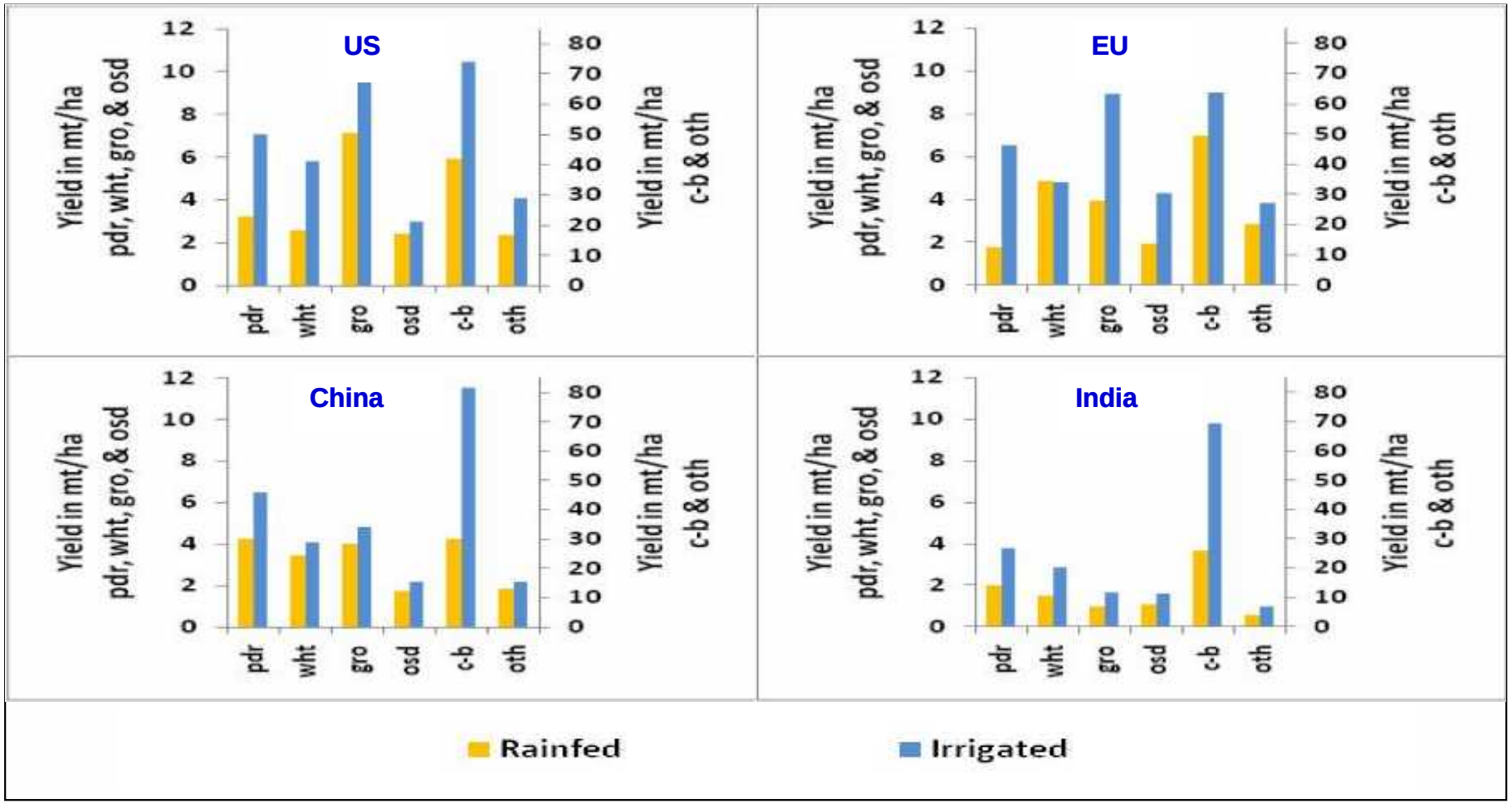
Global distribution of crop production by irrigation type



Irrigated production accounts for more than 40% of total crop production

Role of irrigation in agriculture (5)

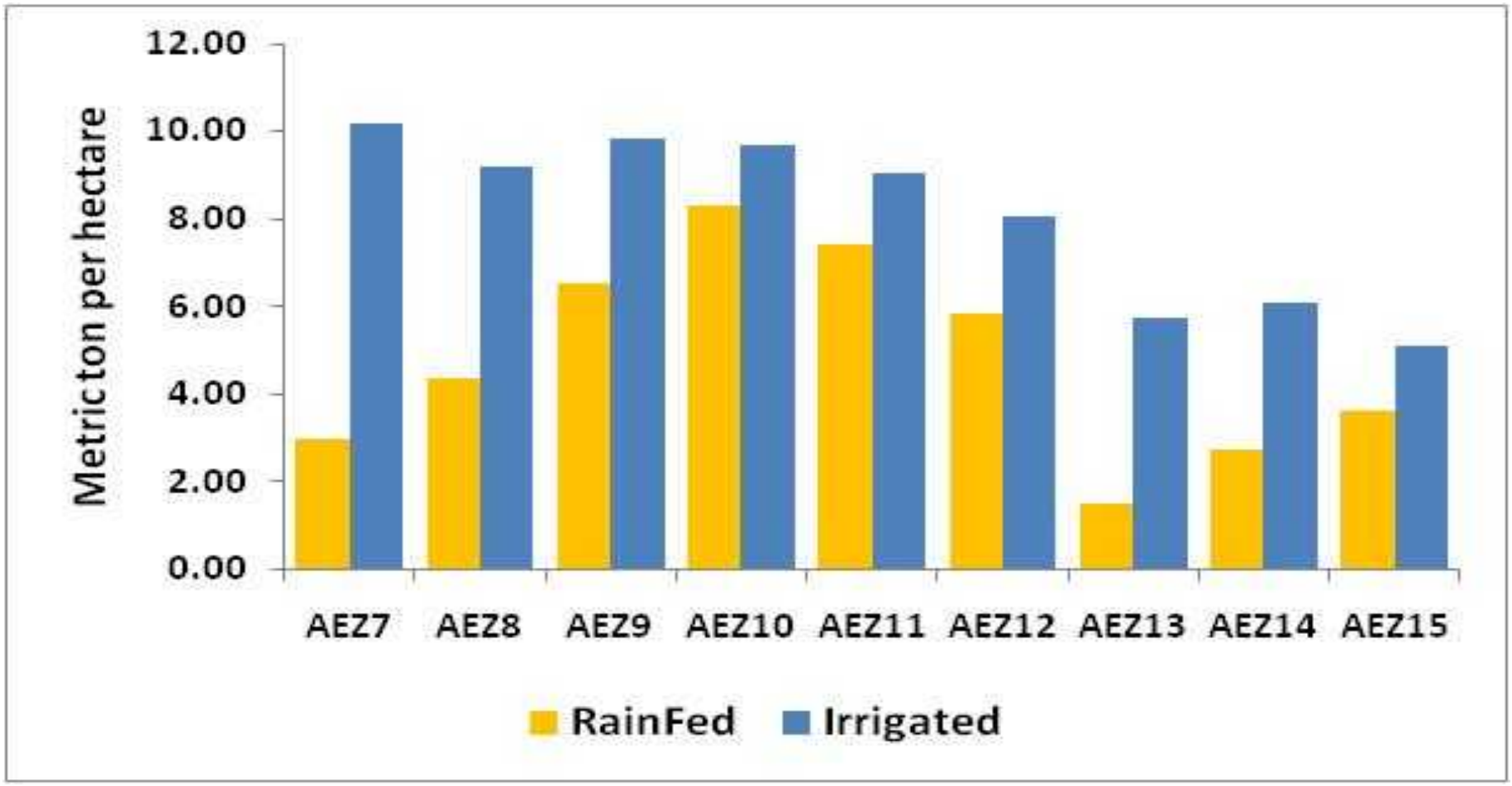
Irrigated & rainfed yields by crop types for selected regions



Irrigated yields are generally much higher than rainfed

Role of irrigation in agriculture (6)

USA coarse grains yields by irrigation type and AEZ



Yields vary greatly by AEZ as well

Data base construction

- **PSD data set classifies global crop production and harvested area into 29 crop categories at 5 minutes spatial resolution by irrigation type.**
- **We used PSD dataset to split the GTAP data set on harvested area and crop production into irrigated and rainfed categories.**
- **Then we divided each and every crop industry of GTAP into two distinct industries of irrigated and rainfed.**

Modifications in GTAP-BIO model

- **In this paper we modify the GTAP-BIO model so that each crop could be produced by two different industries,**
- **Major modifications are:**

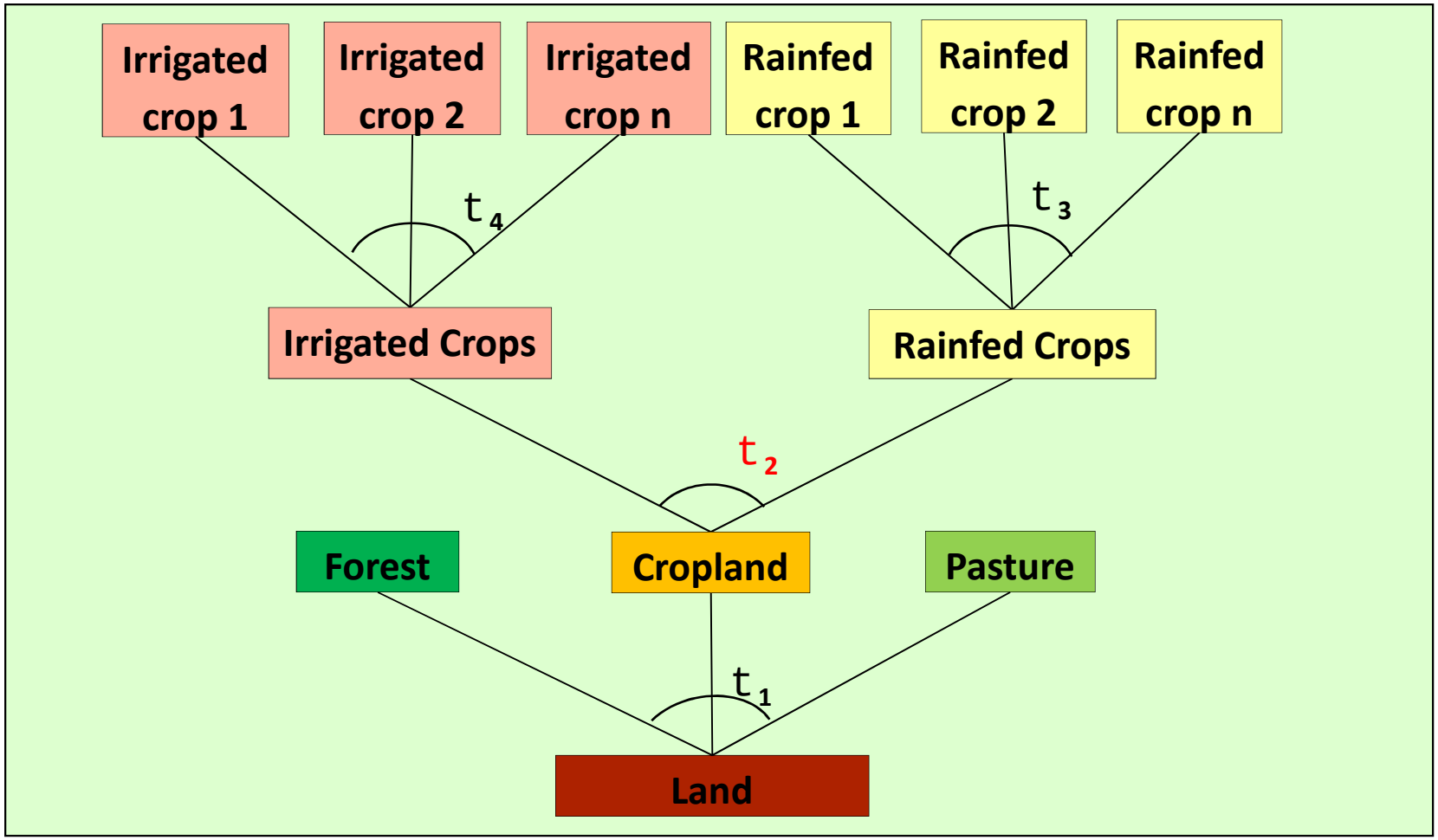
$$pi_{irrigated_j} = pi_{rainfed_j} = ps_j, \ for\ all\ j \in set\ of\ crop\ commodities,$$

$$pi_j = \sum_{k \in top\_com}^{K} S_{jk} * pf_{jk} \ for\ all\ j \in crop\ industries\ set,$$

$$qf_{jk} = qi_j - \varepsilon[pf_{jk} - pi_j] \ for\ all\ k \in top\_com\ set\ and\ all\ j \in crop\ industries\ set,$$

$$qo_c = \sum_{w \in irrigated, rainfed} supplyshr_{cw} * qi_w \ for\ all\ c \in crop\ commodity\ set.$$

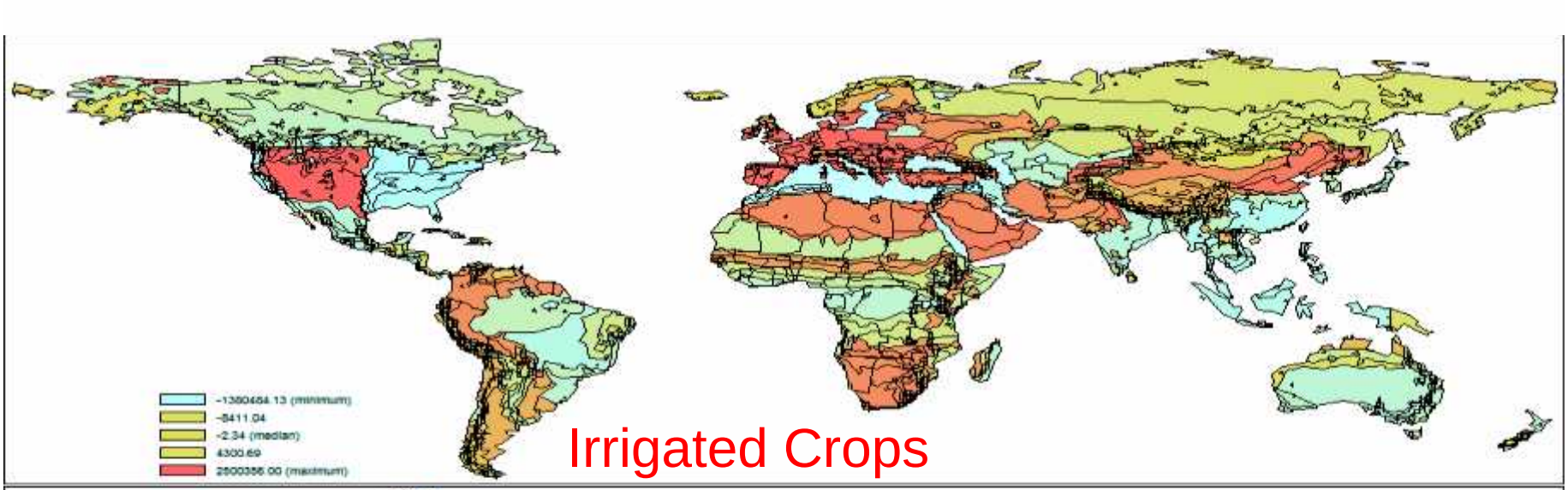
Land supply structure

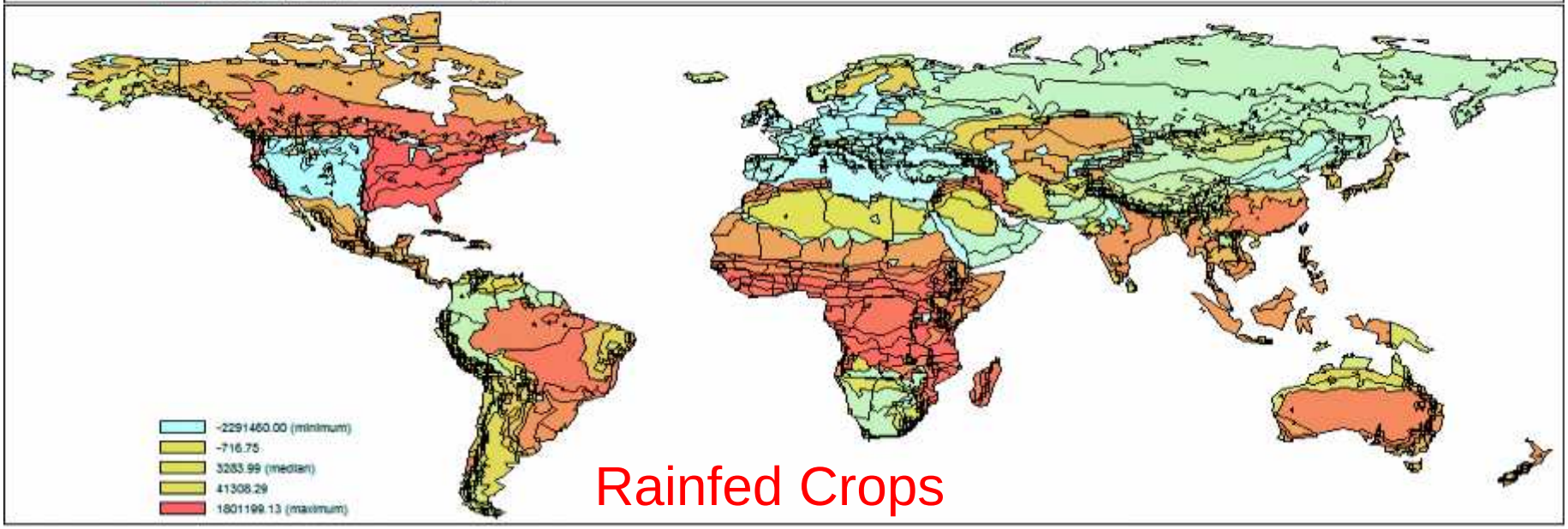


Simulation scenarios

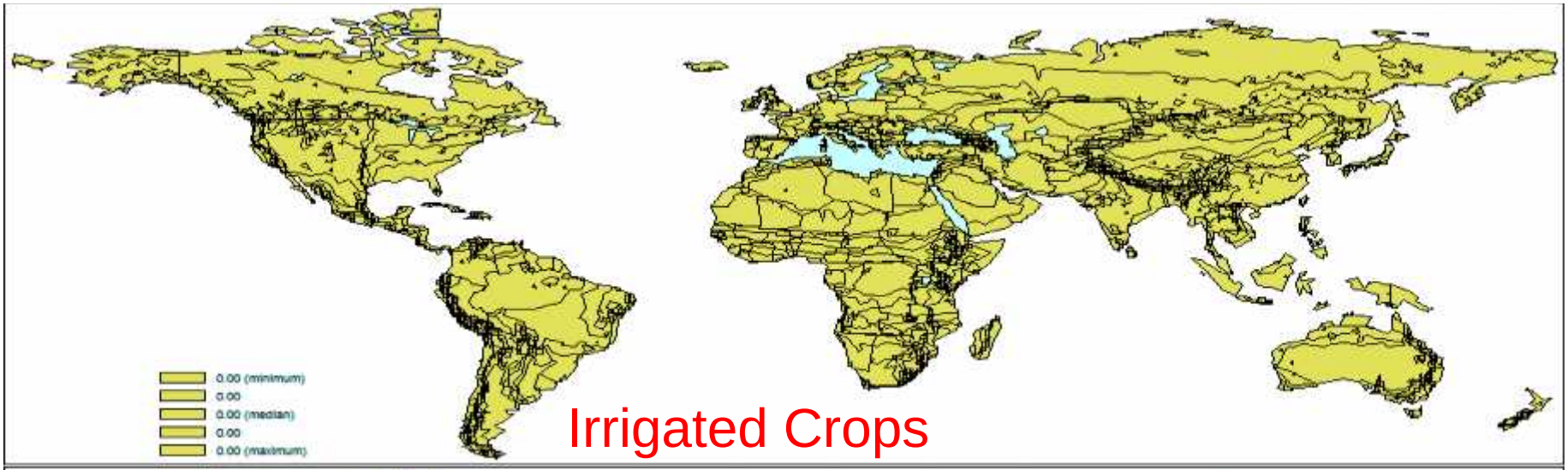
- **Unconstrained case:**
  - **Cropland is mobile between irrigated and rainfed areas, within AEZ,**
  - **Can expand irrigated area at expense of rainfed or vice versa.**
- **Constrained case:**
  - **Irrigated crops compete for fixed area,**
  - **Rainfed cropland expand (or contract) into pasture/forest.**
- **Ignore irrigation:**
  - **Here we simulate earlier studies which have co-mingled irrigated and rainfed cropland, so expansion of area is effectively an expansion of the average.**
- **In these cases we shocked US ethanol to produce 15 BG (the mandated level for 2015).**

Land use changes – no constraint (1)

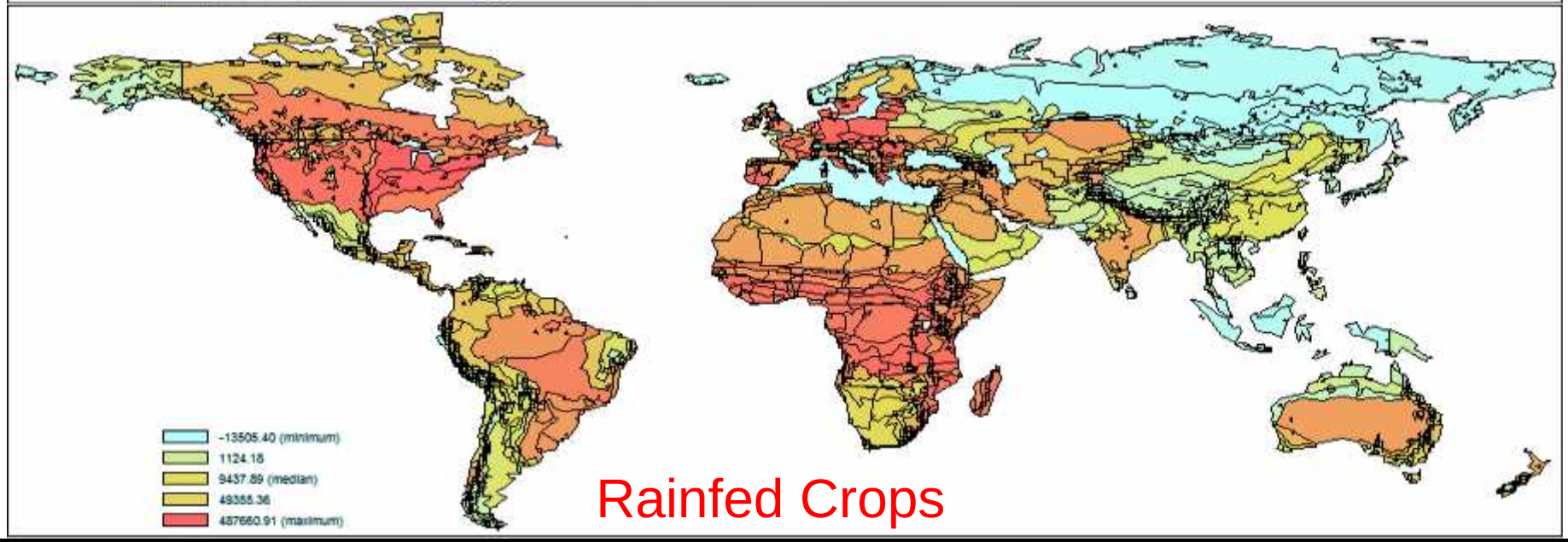




Land use changes – constraint (2)



Irrigated Crops



Rainfed Crops

Cropland changes in 1000 hectares (3)

Region	No Constraint	Mingle	Constraint
USA	1235	1345	1397
EU27	312	400	464
BRAZIL	212	270	312
CAN	372	406	449
JAPAN	-4	0	2
CHIHKG	34	42	48
INDIA	77	87	105
C_C_Amer	81	95	107
S_o_Amer	127	149	167
E_Asia	1	1	2
Mala_Indo	0	-1	-2
R_SE_Asia	5	4	4
R_S_Asia	21	23	28
Russia	-8	-7	-5
Oth_CEE_CIS	83	175	233
Oth_Europe	5	6	6
MEAS_NAfr	95	106	153
S_S_AFR	700	852	1013
Oceania	131	127	151
Total	3478	4081	4633

Cropland expansion increases as the constraint is enforced

Changes in irrigated areas 1000 hectares (4)

Region	No Constraint	Mingle	Constraint
USA	1052	140	0
EU27	953	136	0
BRAZIL	-72	-11	0
CAN	-121	1	0
JAPAN	-42	-9	0
CHIHKG	130	38	0
INDIA	41	17	0
C_C_Amer	-165	-8	0
S_o_Amer	8	12	0
E_Asia	-22	-2	0
Mala_Indo	-58	-19	0
R_SE_Asia	-95	-27	0
R_S_Asia	-8	6	0
Russia	9	-1	0
Oth_CEE_CIS	417	96	0
Oth_Europe	-3	0	0
MEAS_NAfr	-63	42	0
S_S_AFR	49	34	0
Oceania	-222	-5	0
Total	1785	440	0

Changes in land use emissions (5)

Simulations	Annual LUC Emissions (grams of CO2 equivalent per gallon of fuel)			
	Forest	Grassland	Total	Deviation from mingle
No Constraint	1583	730	2313	-13.4
Mingle	1797	874	2671	0.0
Constraint	1987	994	2981	11.6

Conclusions

- **Understanding the potential for expansion of irrigated areas critical for estimation of indirect land use impacts of biofuels**
- **If irrigated area could be expanded in all AEZs, worldwide, induced land use change from biofuels would be sharply reduced**
- **Assuming irrigated area is constrained globally, then a model which abstracts from the irrigation-rainfed distinction will underestimate the induced land use changes due to US ethanol program.**
- **As irrigation constraints are relaxed, then cropland requirements for meeting biofuel expansion are reduced**
- **Future research in this area needs to explicitly model the potential for irrigation expansion on a global scale**

Next Steps

- **Incorporate water into the model:**
  - **Harvested areas and crop production are provided at the AEZ-River basin level,**
  - **Water used by crops at the AEZ-Rive Basin are provided,**
  - **Water supply is fixed,**
  - **A model is developed which handles competition for water and land.**
- **Supply of water can be expanded through investment in infrastructure.**
- **Competition for water among crops and non-crop industries will be included.**

Thank you!

Questions and Comments