GTAP-SIMPLEG: An Integrated Model for Coupling Gridded Land Use, Crop Production and Environment Impacts with Global Supply Chain and Bilateral Trade System

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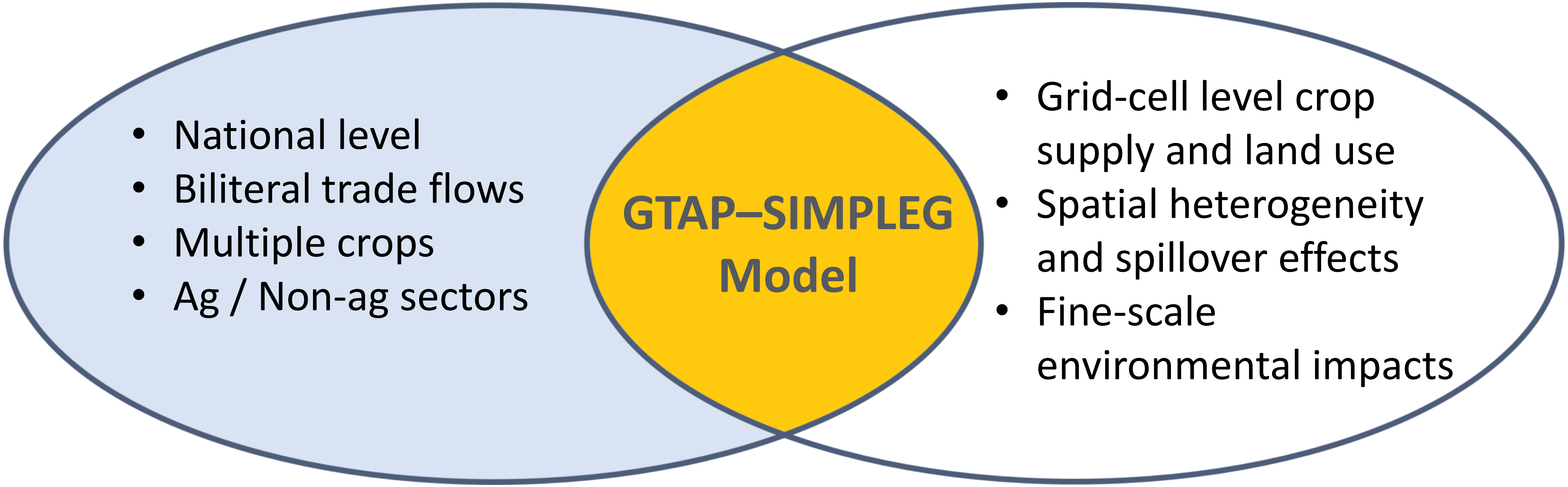
Summary

GTAP

GE model focusing on national economy and trade

SIMPLE-G

PE model focusing on gridded crop production and factor use



- **Model structure, Database and parameter calibration**
- **Application: the impact of soybean trade on Brazil agriculture and land use**

Motivation

Complexity of addressing economic and environmental challenges: **multi-scale drivers, responses and their interactions**

Importance of the **Global-Local-Global framework:**

- Global (national) drivers:
  - Trade, policy, socio-economic development
- Local (spatial) heterogeneity:
  - Gridded data on land, water, crop
- Local specific mechanism:
  - Mobility of factors, spatial spillover effects

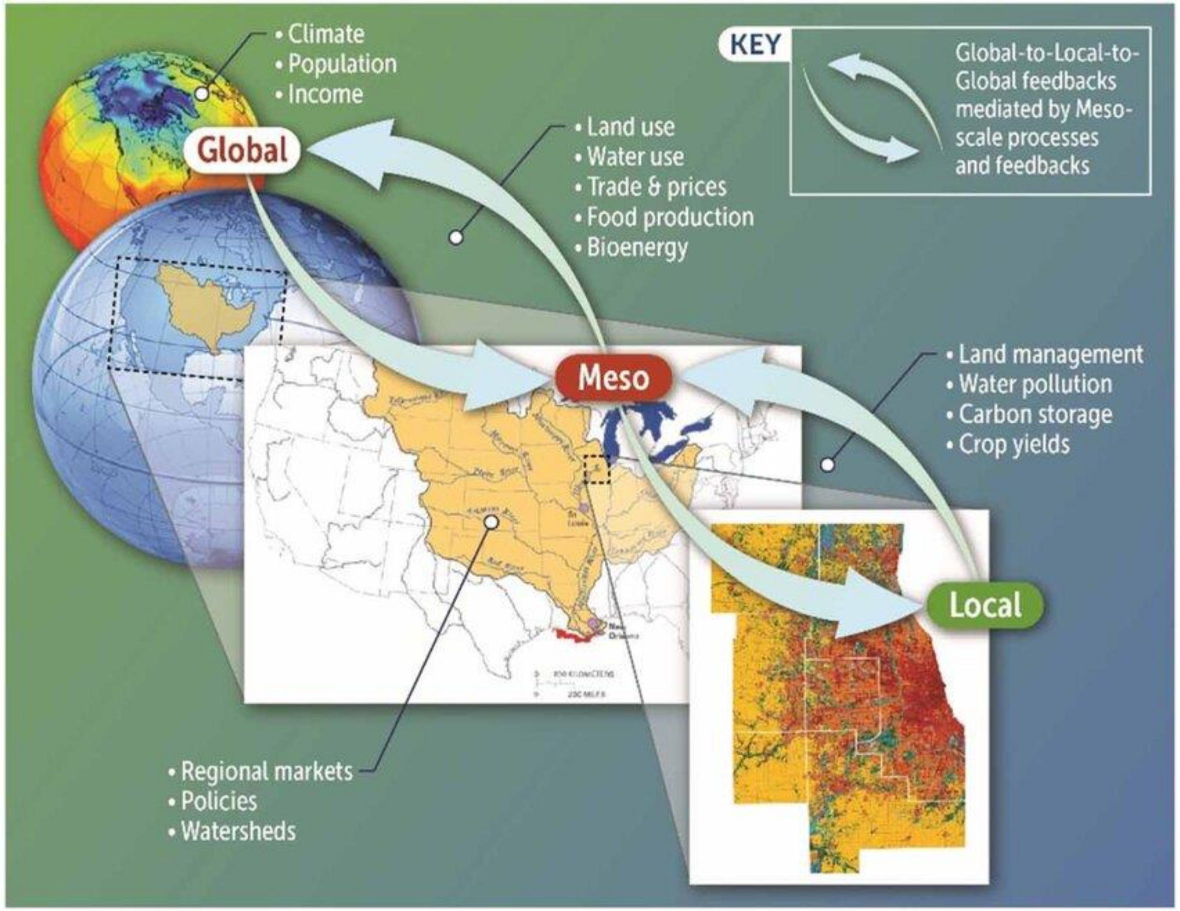


Fig.1. The GLG framework (Hertel et al. 2023)

Motivation

Example: **the soybean trade nexus between the US, Brazil and China**

- Global drivers: China's retaliatory tariffs on soybean produced from the US (Li, et al. 2019)

- National responses: record high soybean production and export in Brazil (Colussi et al. 2024).

- Existing studies focus on direct impacts on the US and China (e.g. Li et al. 2019; Itakura 2020) and spillover effects to Brazil (Dhoubhadel, Ridley and Devadoss 2023).

- Local responses remain under-addressed, especially the economic mechanism with fine-scale modeling

Motivation

Development of the GTAP-SIMPLEG model

- The Global Trade Analysis Project (GTAP) model, version 7 (Corong et al. 2017)
- The Simplified International Model of agricultural Prices, Land use and the Environment: Gridded version (SIMPLE-G) (Baldos et al. 2020) and the version for Brazil (Wang et al. 2024).

Table 1. Advantages of GTAP and SIMPLEG

GTAP	SIMPLE-G
• Complicated supply chains (opposed to crop flow only) • Economywide shocks (e.g., trade agreements, climate policy, tax reform) • Biliteral trade flows (not available in SIMPLE-G yet)	• Spatial heterogeneity in responses • Local-specific shocks • Subnational spillover effects • Fine-scale environmental impacts

GTAP-SIMPLEG

Model overview

- GTAP framework + Gridded land use and crop production system (based on SIMPLE-G) embedded
- Baseline year: 2017.   Gridded region: Brazil (can be extended)

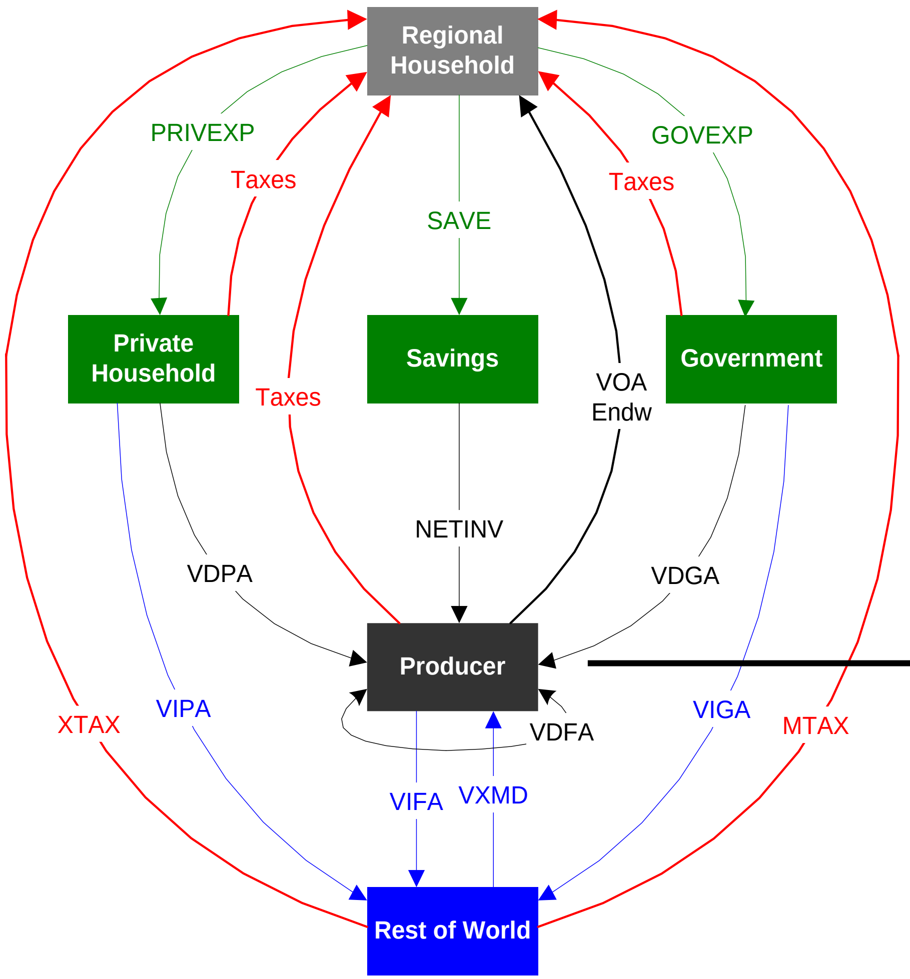
Table 2. Comparison between SIMPLE-G-Brazil and GTAP-

	SIMPLE-G-Brazil	GTAP-SIMPLEG-Brazil
Grids	50,598 (5 arcmin)	103,751 (5 arcmin)
Land use type	1 (cropland)	3 (cropland, pasture, forest planation) (exogenous: natural forest)
Crop type	1 (corn-equivalent)	8 (GTAP crops)
Input type	6 (Fertilizer, land, labor, capital, irrigation water, irrigation equipment)	6 (Intermediate input, land, labor, capital, irrigation water, irrigation equipment)
Equations*	304,867	2,952,726
Time cost	5 minutes, 6 seconds	87 minutes, 56 seconds

*: after condensation

Structure of GTAP-SIMPLEG: non-gridded regions

GTAP multi-region (Brockmeier 2001)



Production system for a certain crop

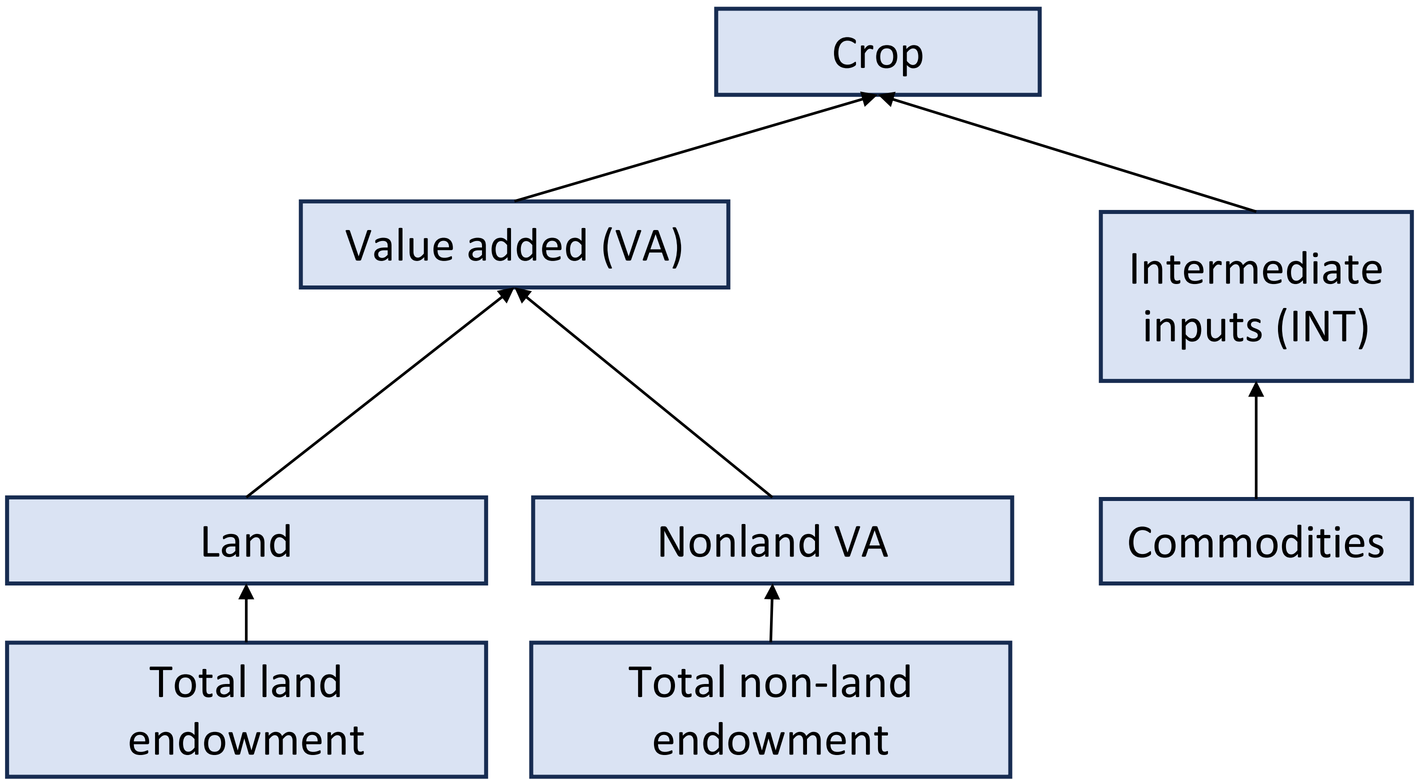
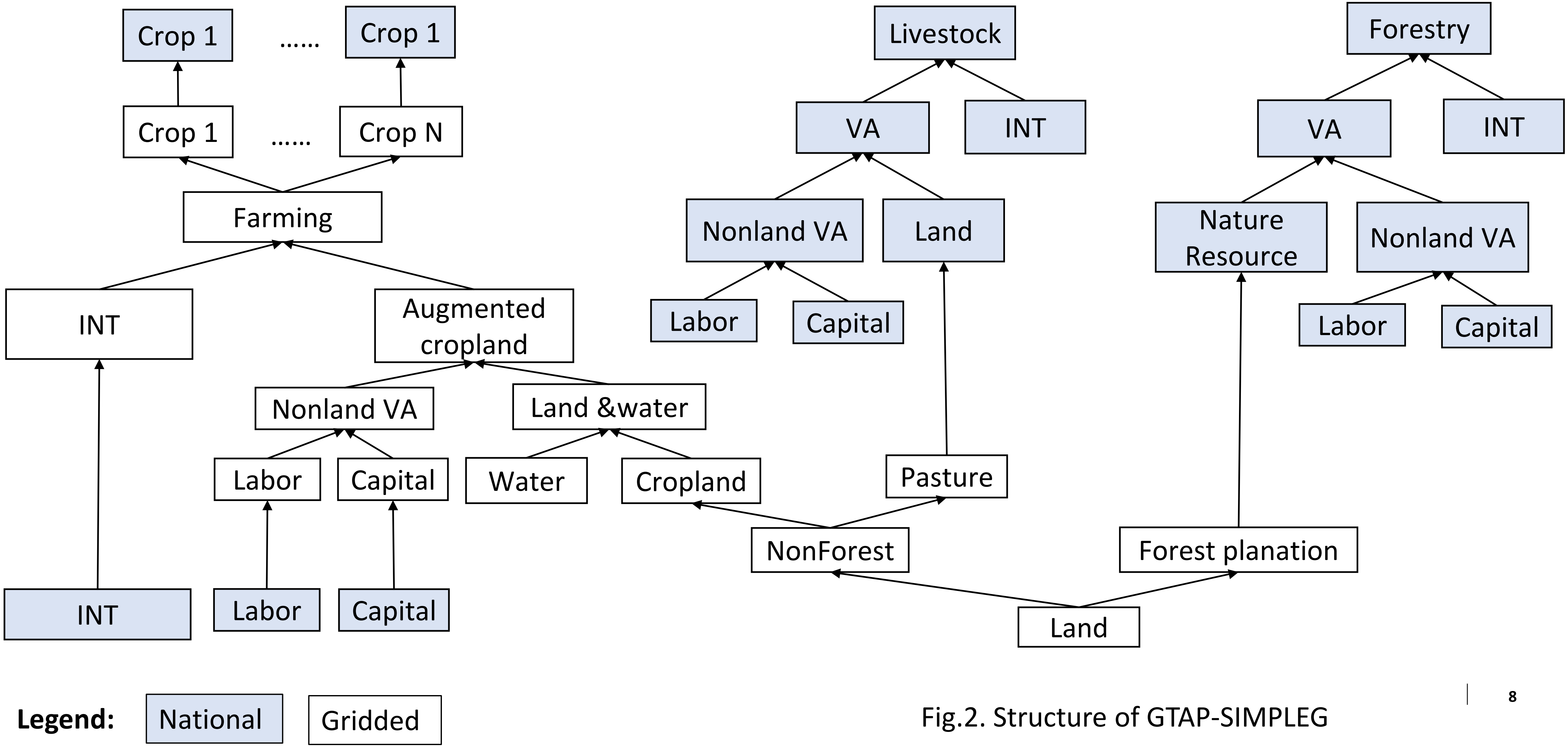


Fig.2. Structure of GTAP-SIMPLEG

Legend: National

Structure of GTAP-SIMPLEG: gridded regions



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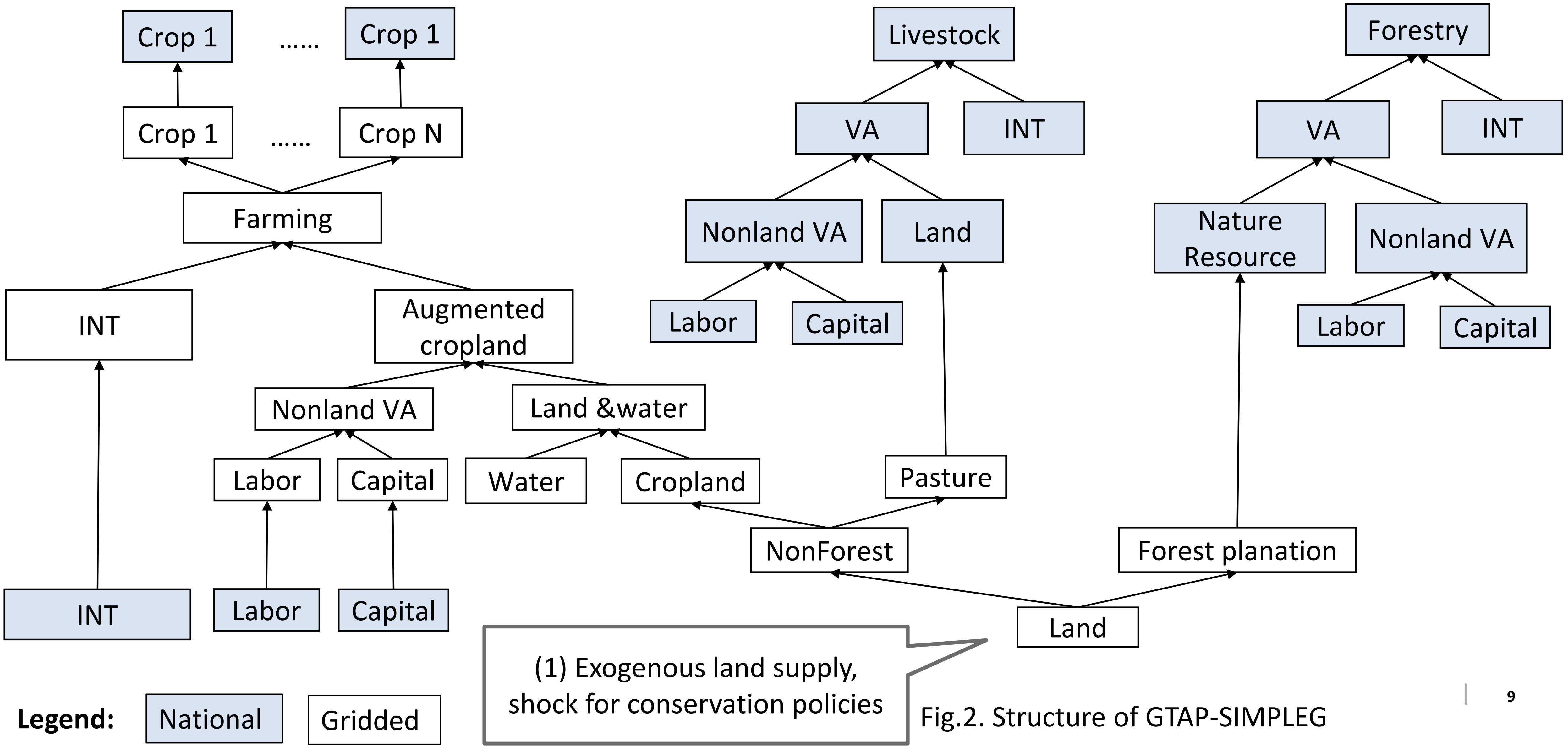
Structure of GTAP-SIMPLEG: gridded regions



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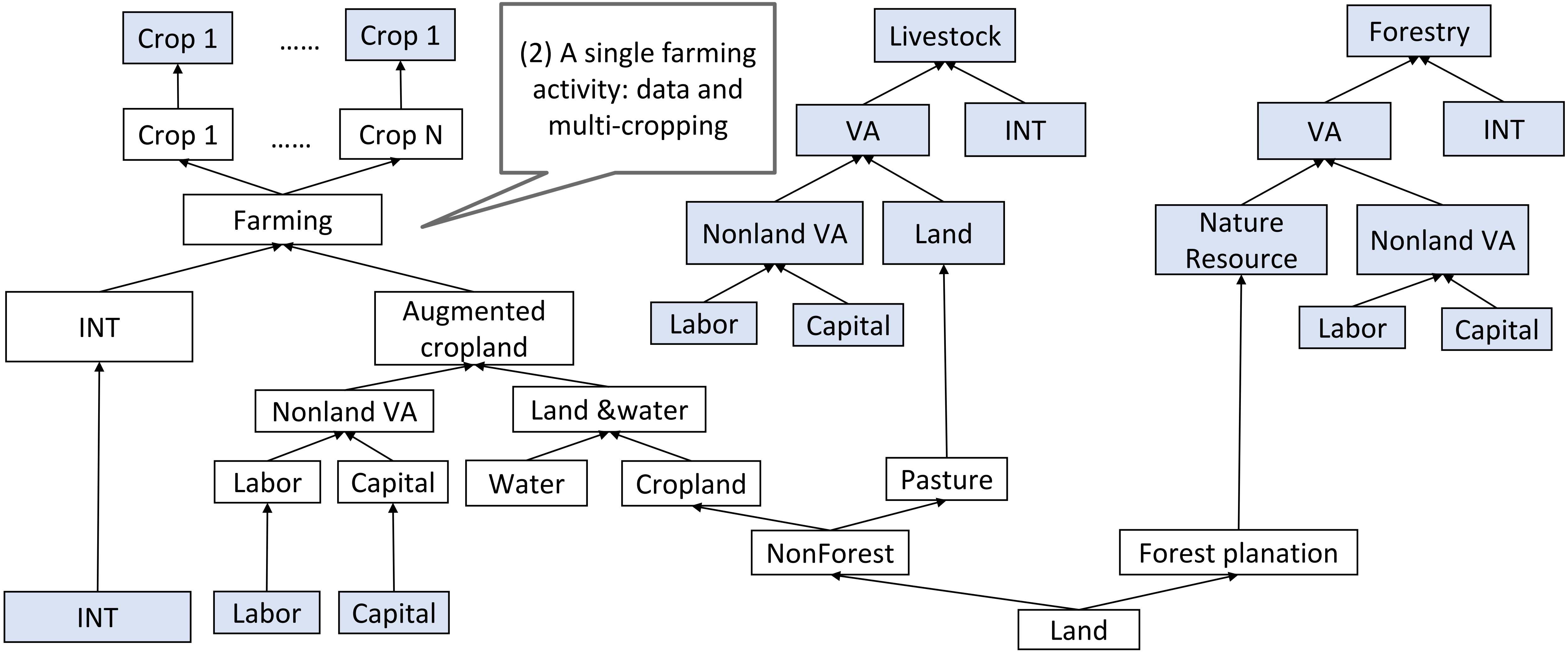
Structure of GTAP-SIMPLEG: gridded regions



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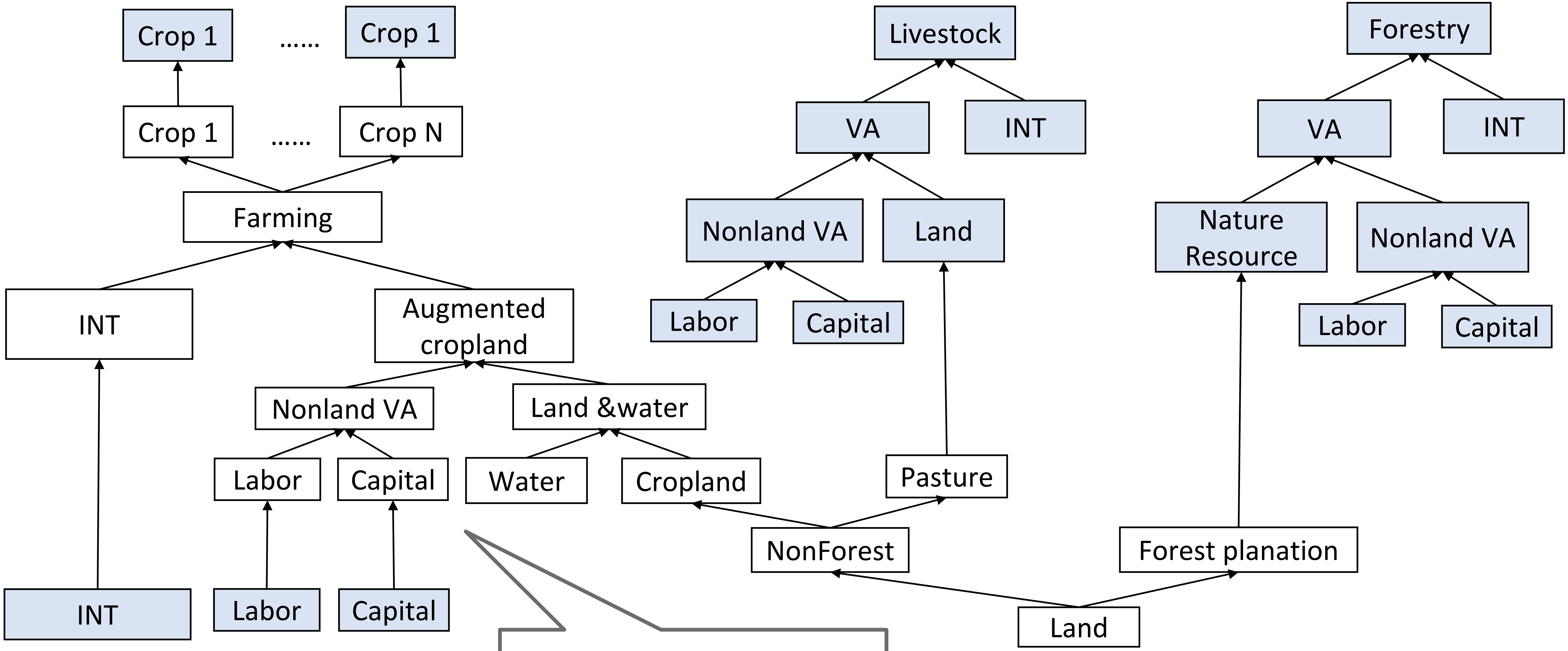
Structure of GTAP-SIMPLEG: gridded regions



(3) Gridded non-land VA and INT: cost share in farming

Legend: National Gridded

Fig.2. Structure of GTAP-SIMPLEG

Data

Gridded land use – Mapbiomas (2020)

- Resolution: 30 meter
- Aggregated to 5 arcmin

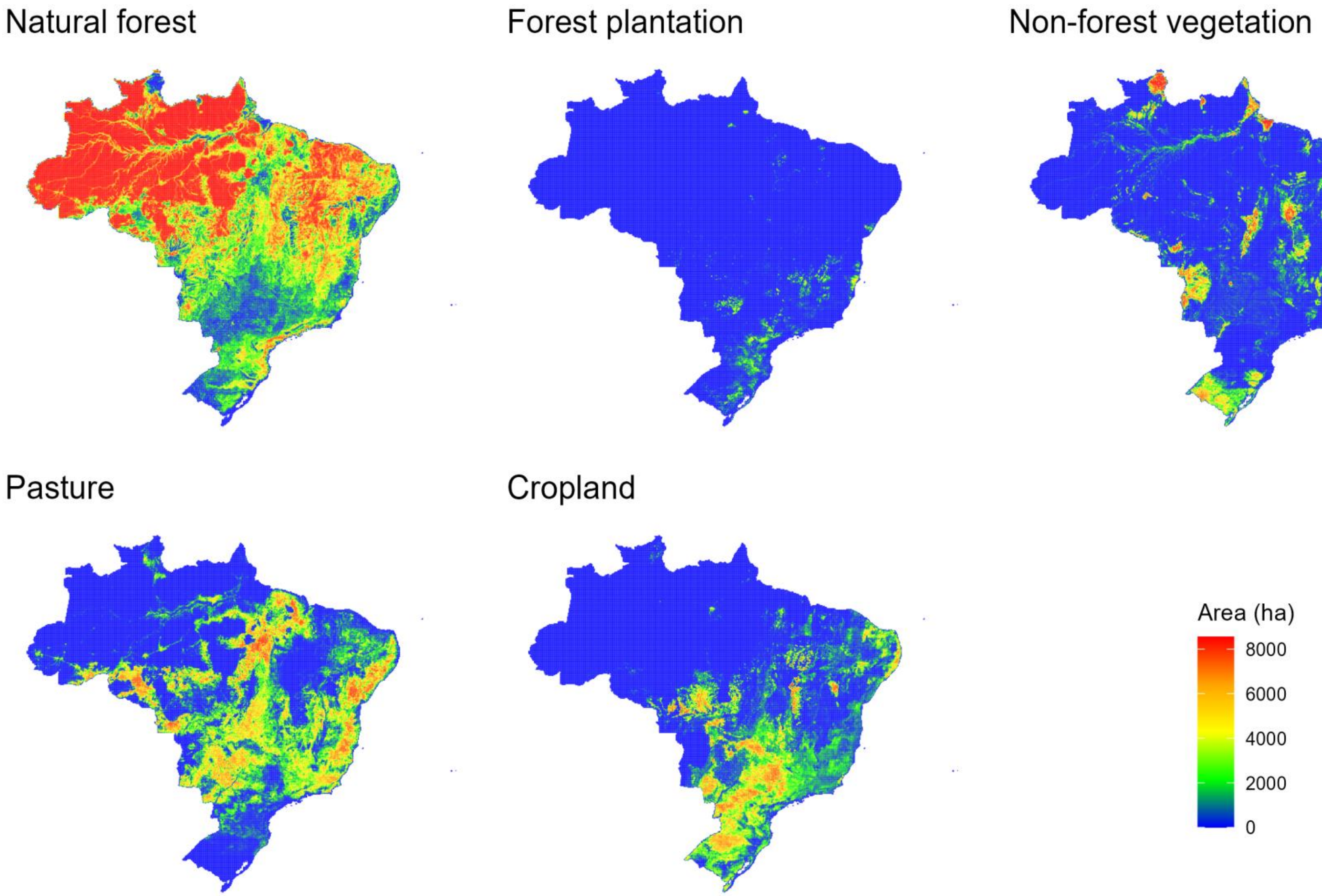


Fig.3. Gridded land use pattern in 2017

Data

Gridded crop production – SPAM2010 (Yu et al. 2020)

- Global coverage
- 42 crops -> aggregate to 8 GTAP crops (Chepeliev 2020)
- By irrigation types
- Apply the pattern to downscale FAOSTAT data (five-year average centered 2017)

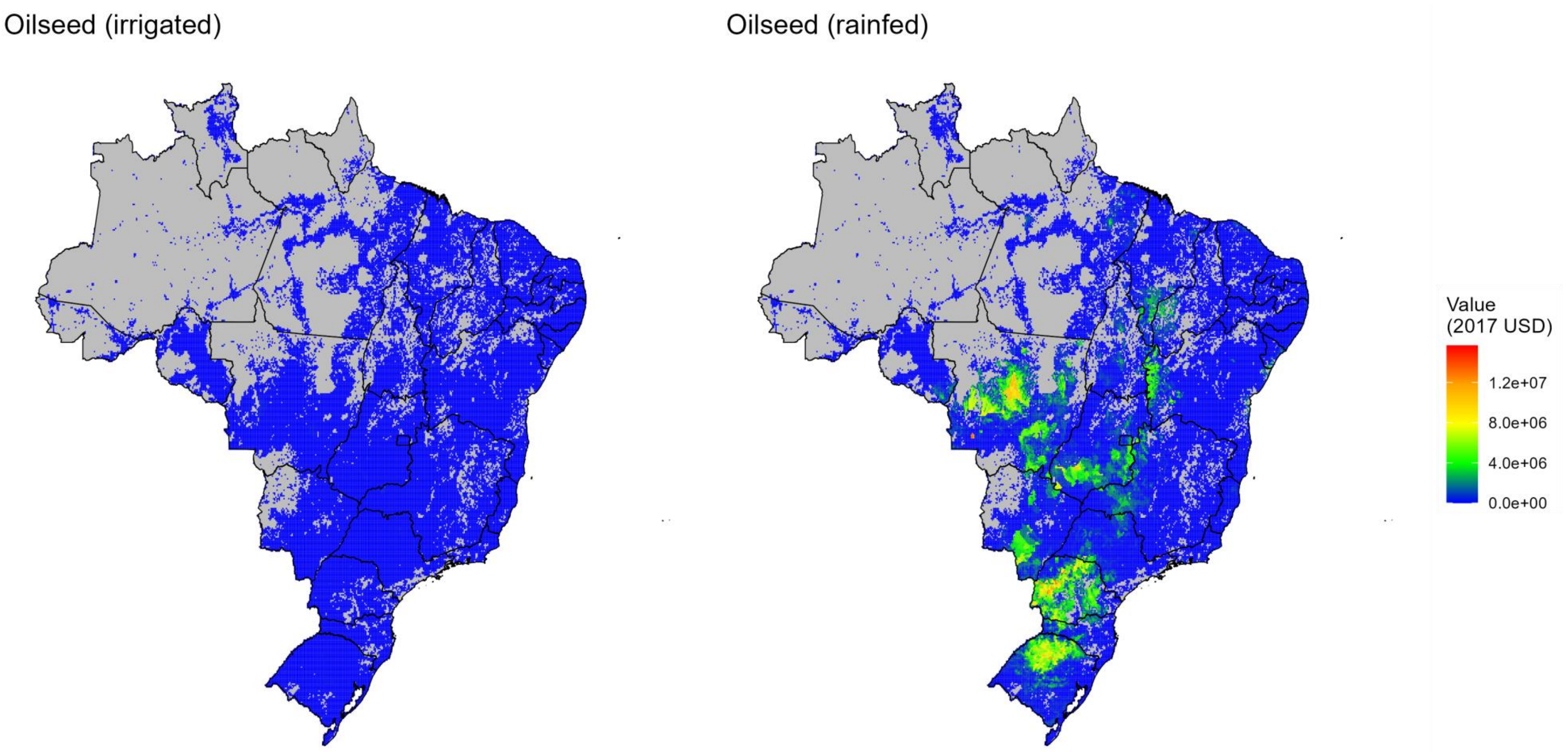


Fig.4. Gridded crop output value in 2017

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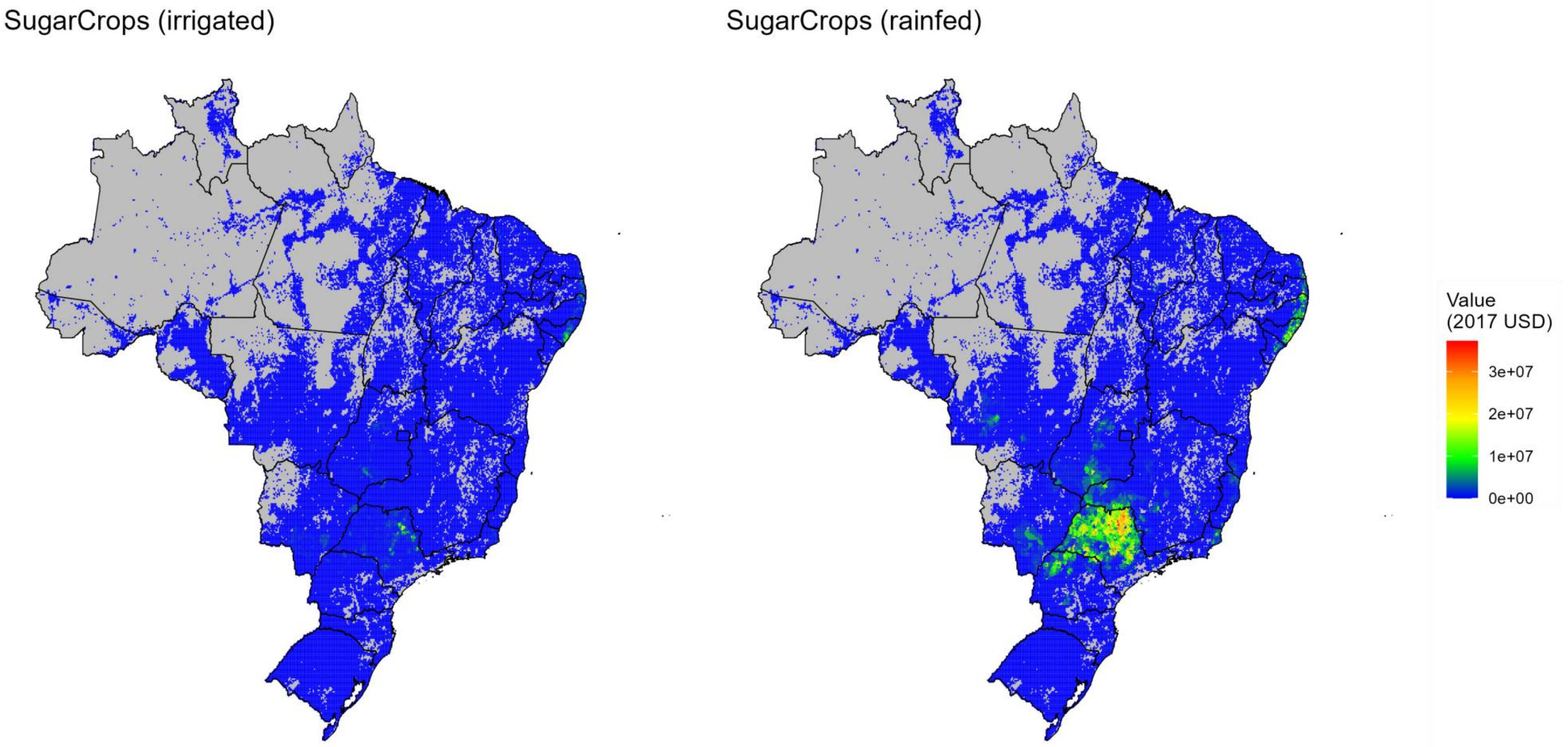

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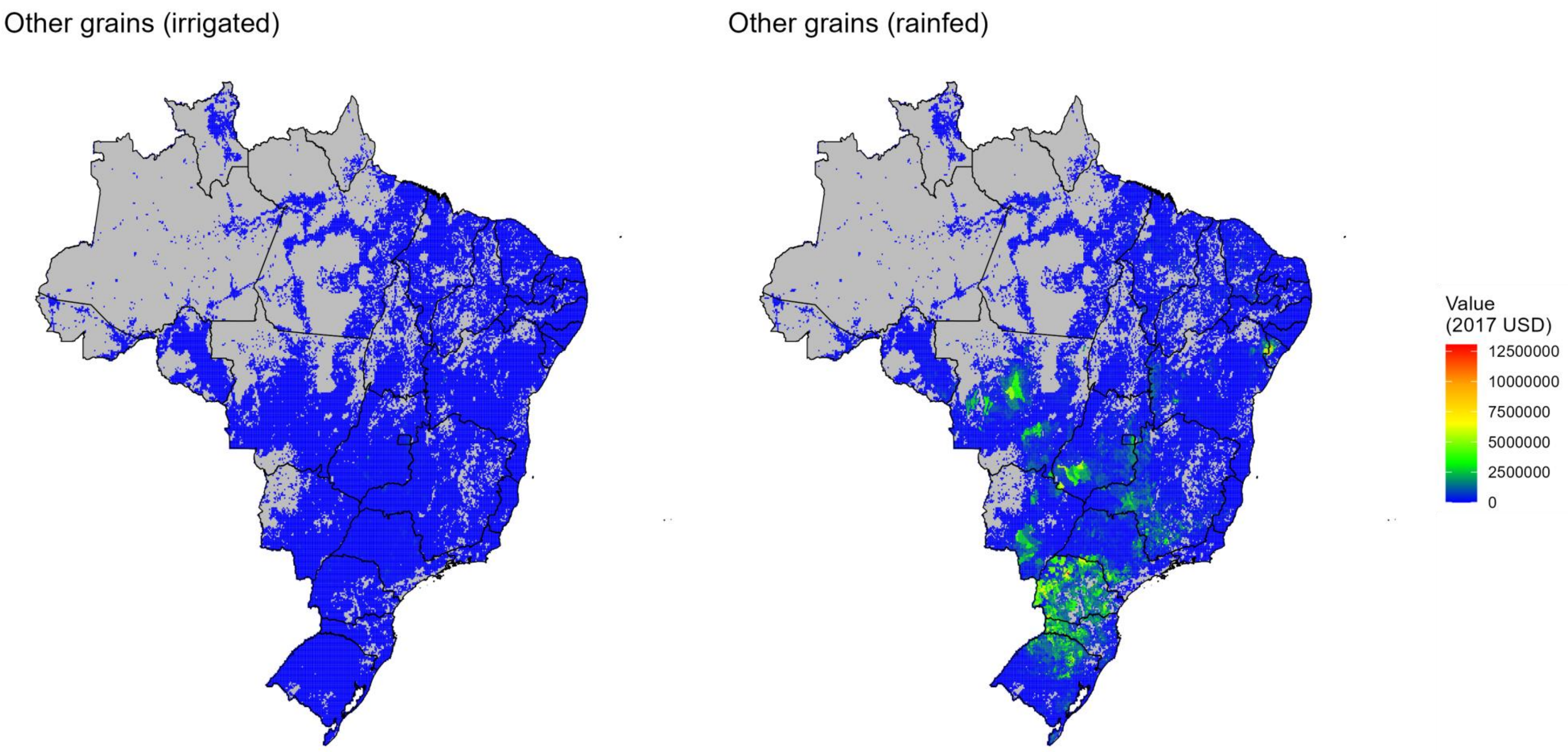

Fig.4. Gridded crop output value in 2017

Parameter calibration

Nelder-Mead Method:
Derivative-free optimization for multiple parameters

- For N dimensions, start with N+1 random parameter vector θ_i (i = 1, 2, …, N+1)
- Run the model for each θ_i , find the θ_i^* with the worst result (highest error)
- Update θ_i^* with other θ_i
- Repeat until:
  - The error is below tolerance
  - Maximum iteration times

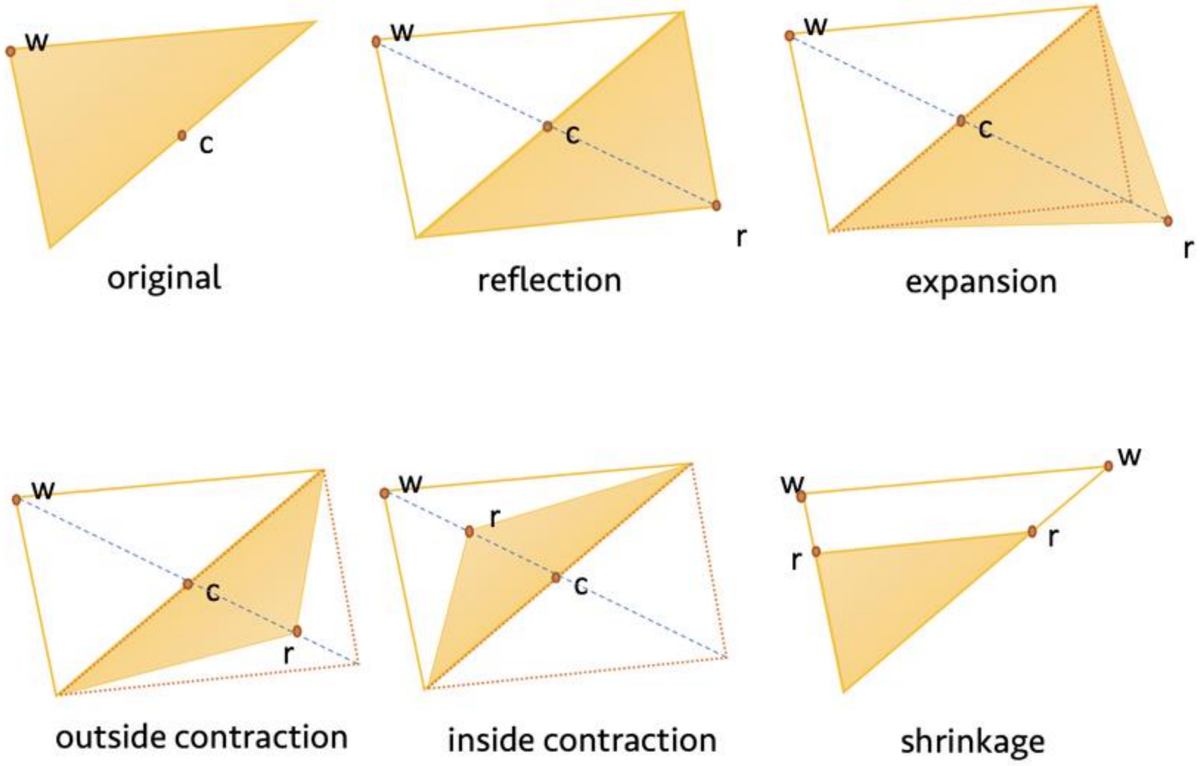

Fig. 5. Operations for update θ_i^* with N = 2 (Jiang et al. 2019)

Parameter calibration

- First step: calibrate ETCP: Elasticity of transformation between pasture and cropland for N states (N = 27)

- Minimize the objective function:

$$\min_{ETCP} \frac{1}{N} \left(w^{cropland} \sum_{i=1}^{N} \left(QCROPLAND_i^{sim} - QCROPLAND_i^{obs} \right)^2 + w^{pasture} \sum_{i=1}^{N} \left(QPLAND_i^{sim} - QPLAND_i^{obs} \right)^2 \right)$$

- w: weight to balance the error between land use types with national area
  - $w^{landuse} = \left(\frac{Q^{pasture}}{Q^{landuse}}\right)^2$

Parameter calibration

- Second step: calibrate ETMC: Elasticity of transformation between multiple crops from farming for N states, with calibrated ETCP
  - Focus on <u>three major crops</u>: oilseeds (osd), other grains (gro), sugar crops (c_b)

- Minimize the objective function:

$$\min_{ETMC} \frac{1}{N}\left(w^{osd}\sum_{i=1}^{N}\left(Qosd_i^{sim} - Qosd_i^{obs}\right)^2 + w^{gro}\sum_{i=1}^{N}\left(Qgro_i^{sim} - Qgro_i^{obs}\right)^2 + w^{c\_b}\sum_{i=1}^{N}(Qc\_b_i^{sim} - Qc\_b_i^{obs})^2\right)$$

- w: weight to balance the error between crops with price
  - $\mathrm{w}^{\mathrm{crop}} = \left(\frac{P^{crop}}{P^{osd}}\right)^2$

- We can repeat the calibration of ETPC with calibrated ETMC

Parameter calibration – land use

Calibration: hindcast from 2017 to 2012 with shocks of :

- Historical crop and livestock price: FAOSTAT (from linear regression)
- State level total land area (cropland, pasture and forest plantation): Mapbiomas

Compare model simulation with observed data:

- Land use area: Mapbiomas

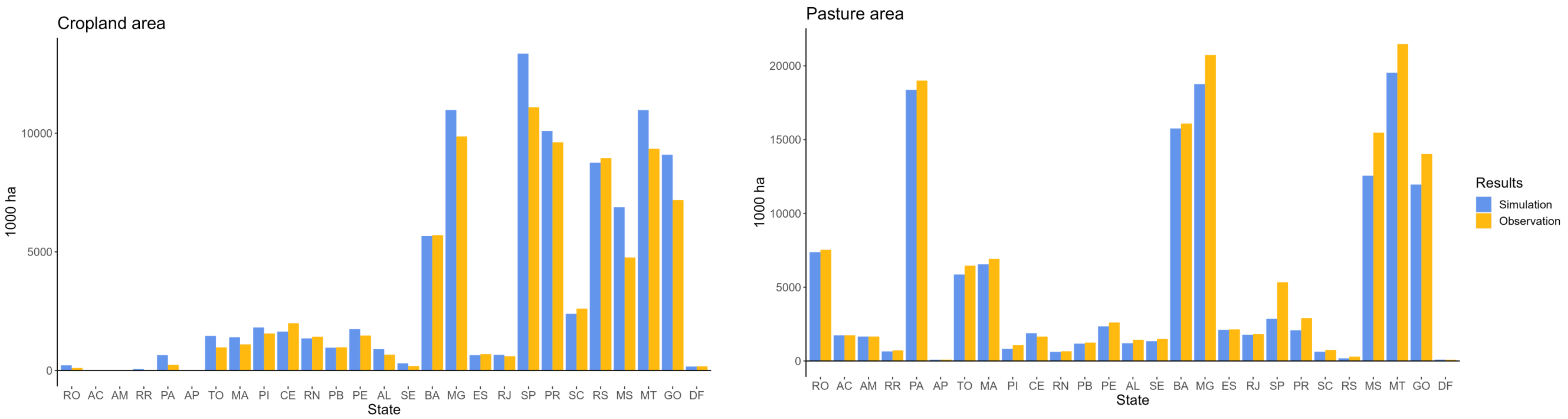

Fig. 6. Simulated and observed land use area in 2012

Parameter calibration – crop output

Compare model simulation with observed data:

- Crop output quantity: % change from Brazilian Institute of Geography and Statistics (IBGE) + baseline data

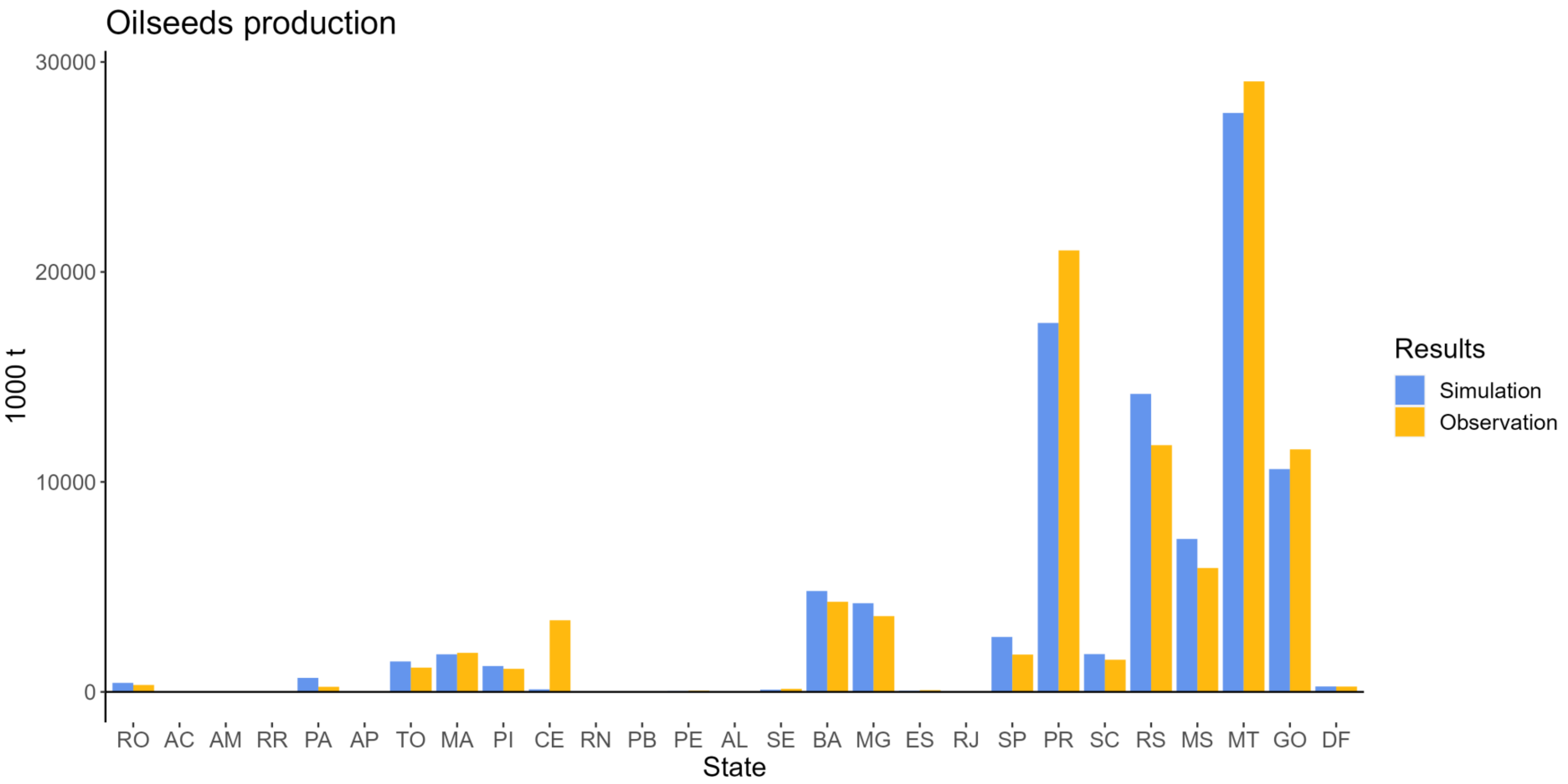

Fig.7. Simulated and observed crop production in 2012

Parameter calibration – crop output

Compare model simulation with observed data:

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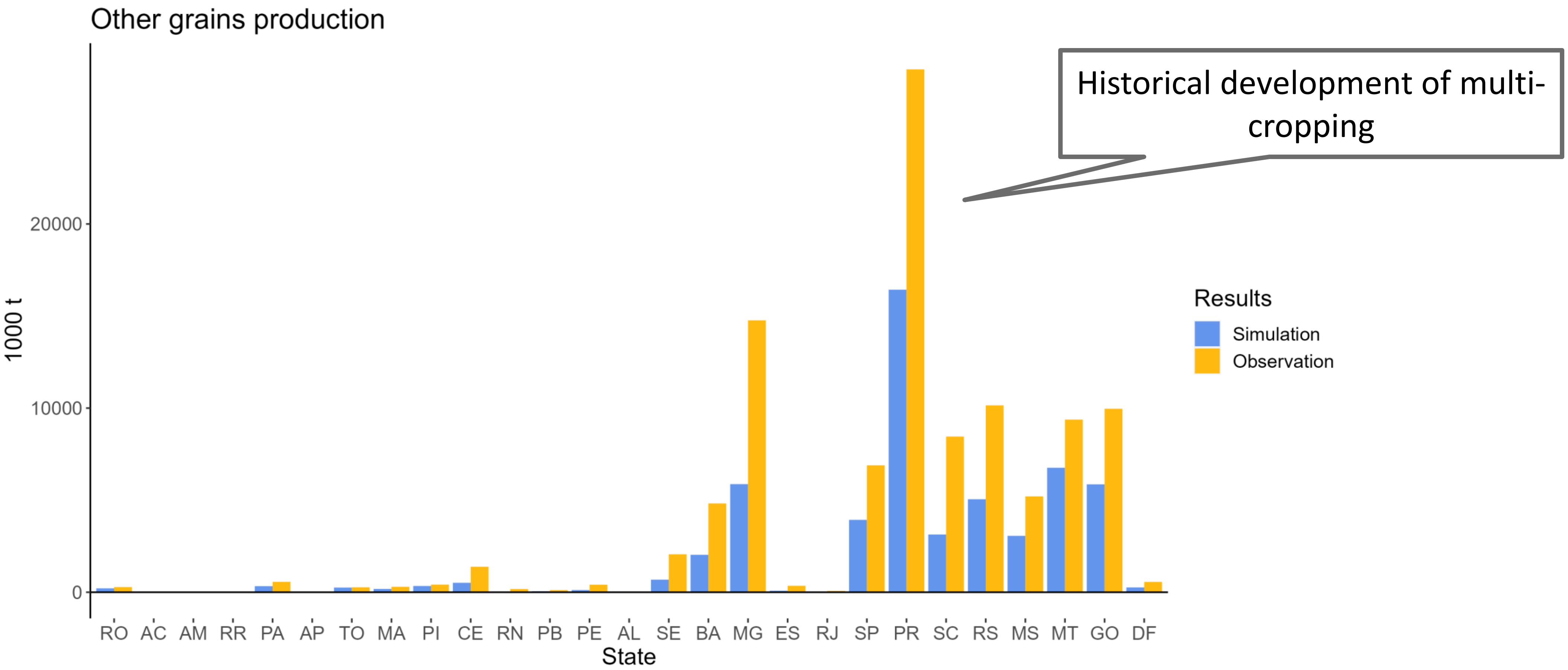

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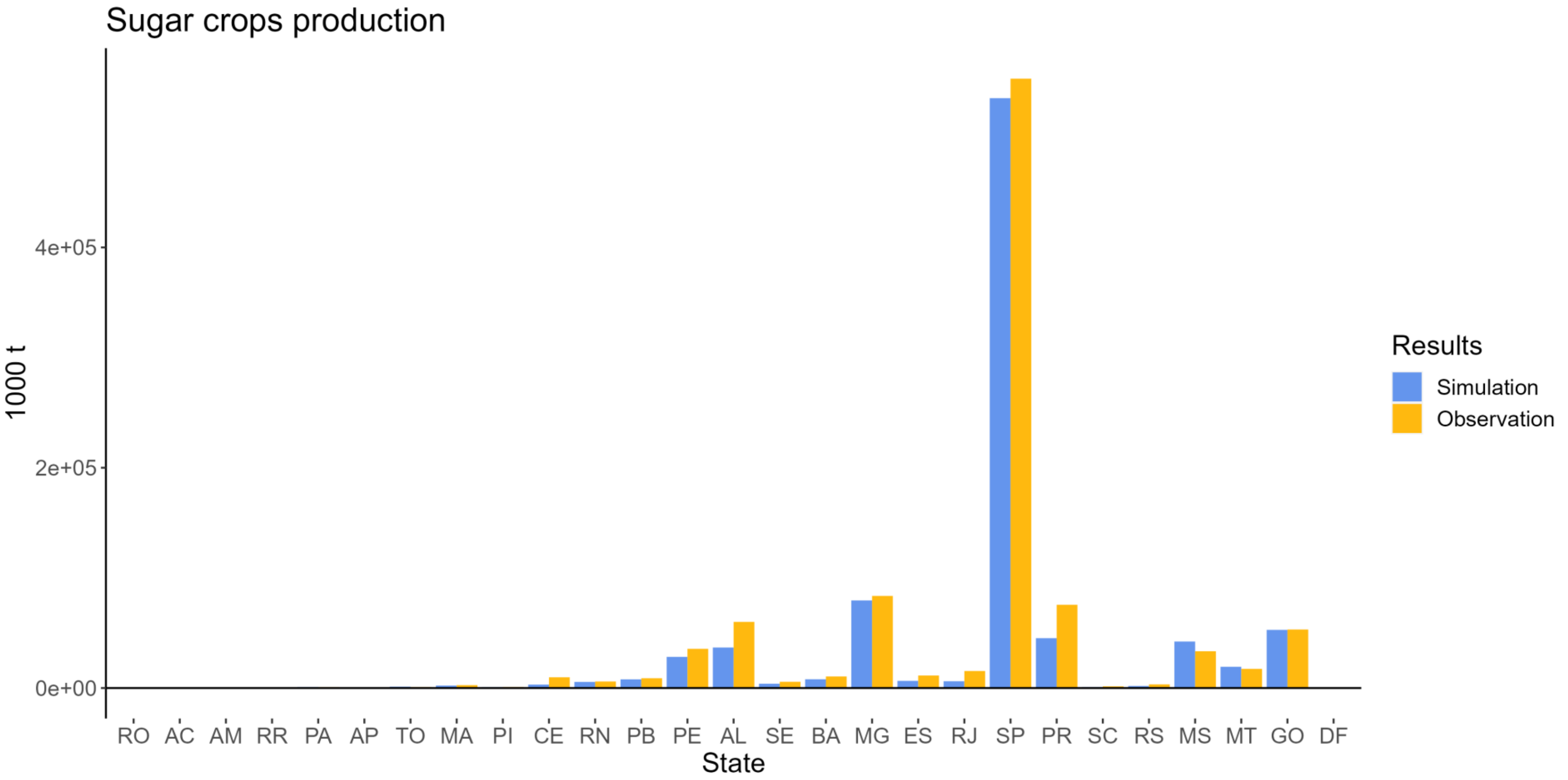

Fig.7. Simulated and observed crop production in 2012

Preliminary results – crop output

Experiment: China's 25% tariff on US's soybean export

- Oilseed: expansion
- Sugar crops: reduction: substitution effect

- Other grains: mainly reduction. Certain region: scale > substitution effect

- Local heterogeneity in response

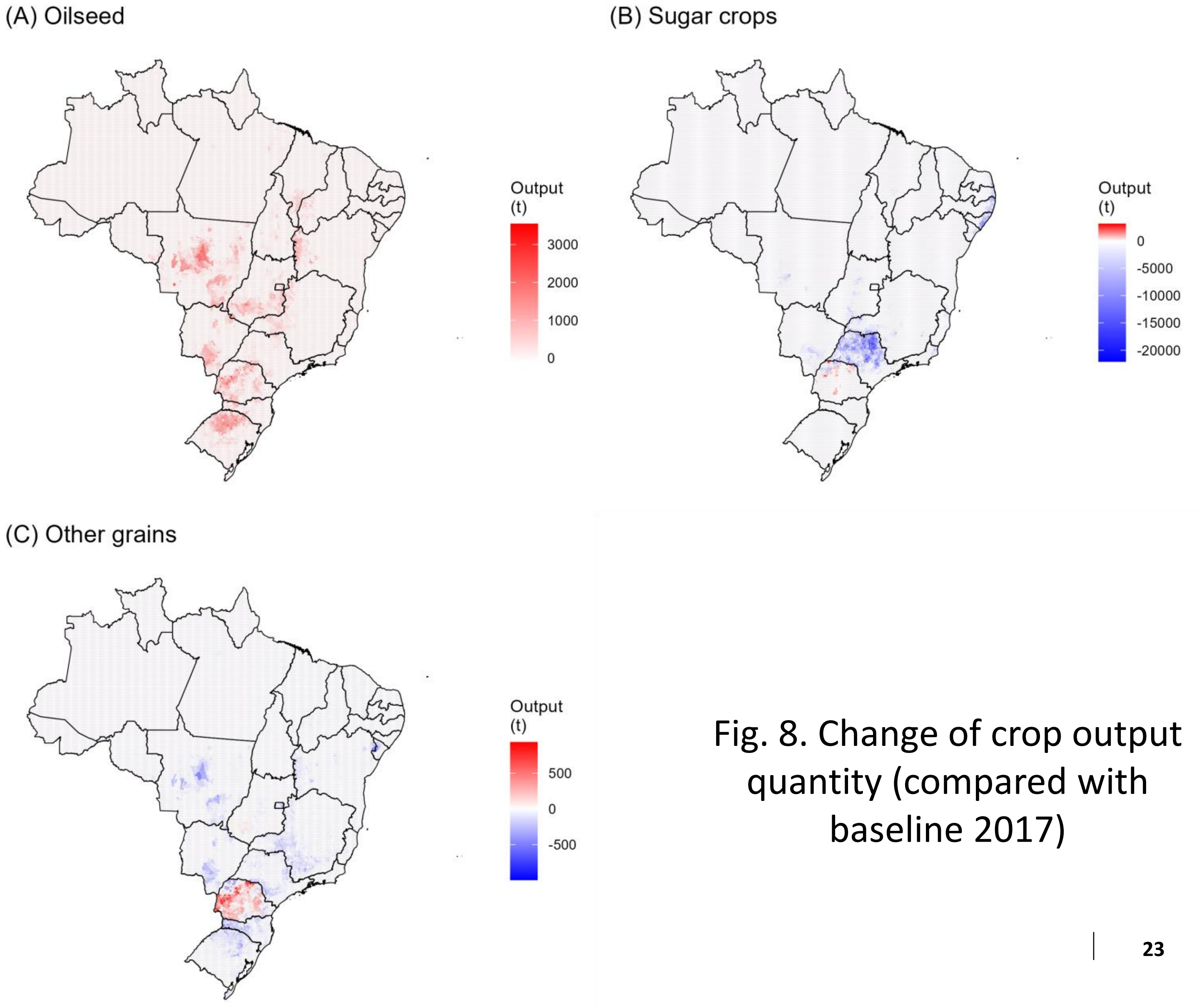

Fig. 8. Change of crop output quantity (compared with baseline 2017)

Preliminary results – land use

Experiment: China's 25% tariff on US's soybean export

Cropland
- Expansion in center region, mainly due to soybean
- Shrinkage in eastern region, mainly due to sugar cane

Pasture
- Opposite pattern where cropland and pasture both exist
- Drives pasture pattern from central to east Brazil

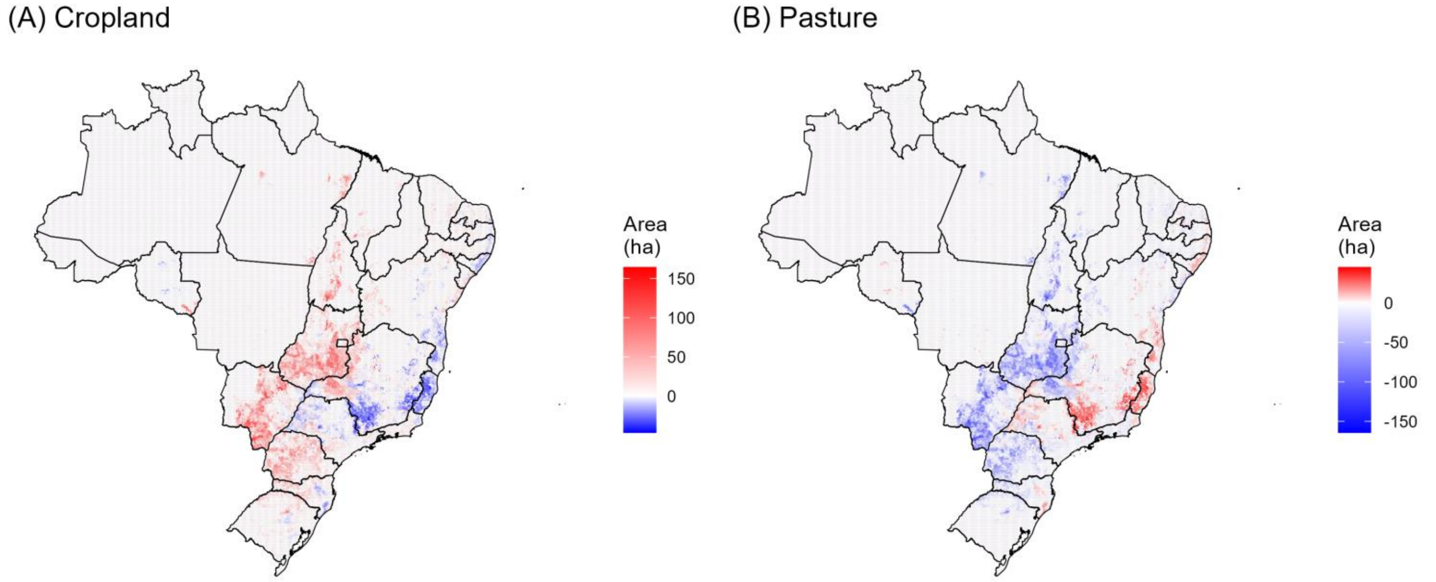

Fig. 9. Change of land use area (compared with baseline 2017)

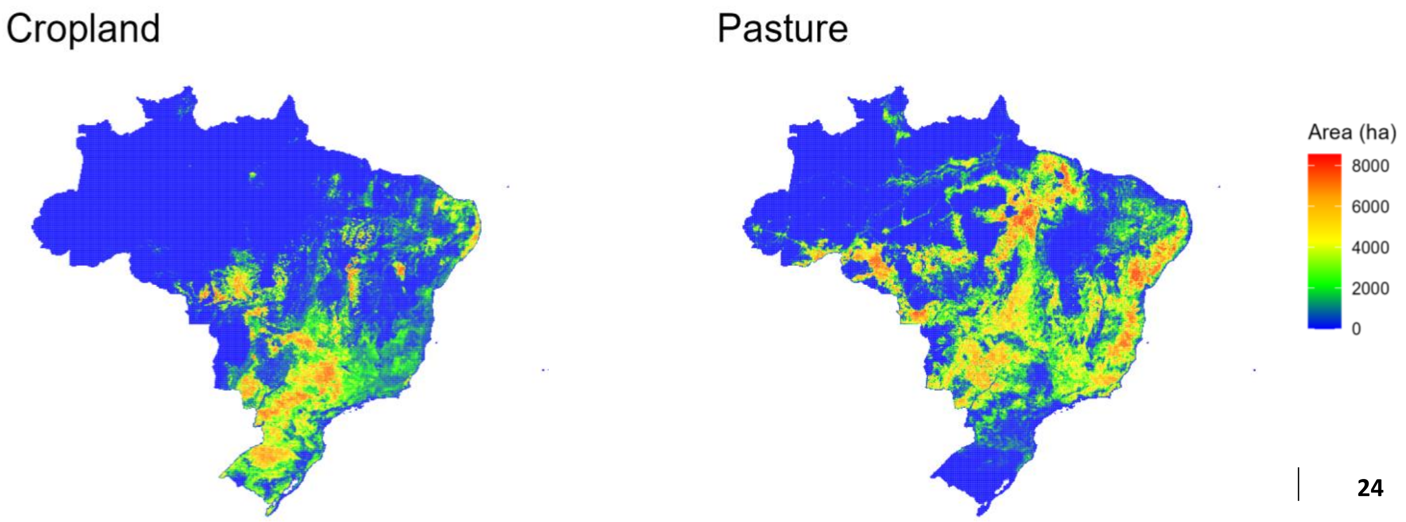

Fig.3. Gridded land use pattern in 2017

Discussion and future directions

- Global tariff shock not only drives the expansion in soybean production nationally, but also reshape the spatial pattern of crop production and land use.

- Findings indicates the importance of spatial level modeling
  - spillover effects across crops and sectors
  - gridded data with spatial heterogeneity.

- GTAP-SIMPLEG model shows great potential of integrating global and local level analysis. Besides trade shock, it can also be used to research:
  - Shocks from non-ag sectors (from example biofuel demand)
  - Local-specific shocks (for example conservation policy or infrastructure)
  - Local environmental implications (gridded carbon emission, biodiversity or other ecosystem services)

- The model can be updated with the endogenous natural forest demand
  - With cultivation cost or ecosystem services value

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Thank you!

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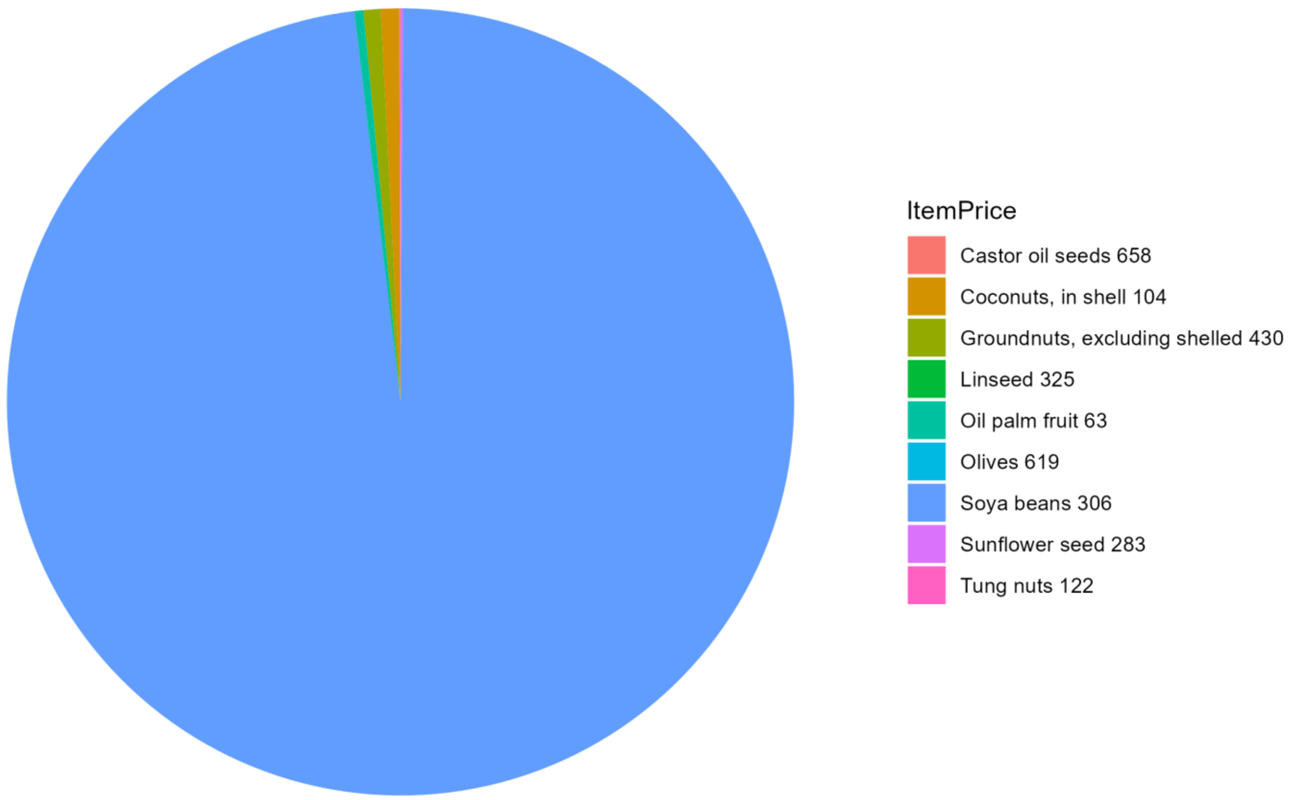
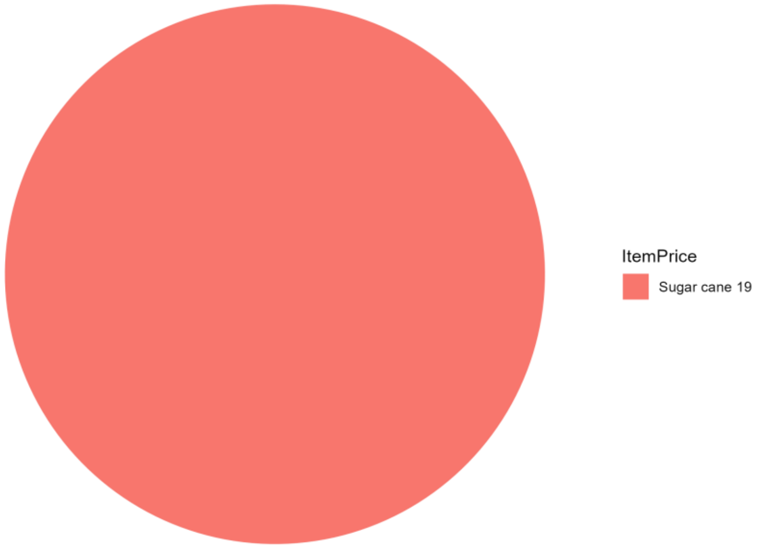
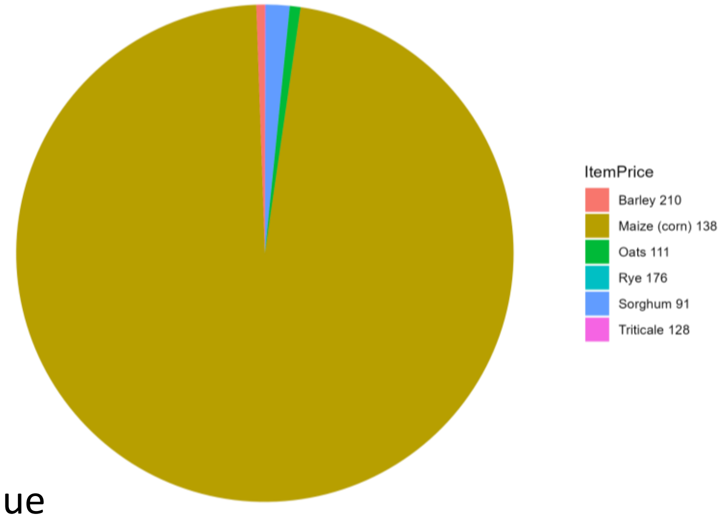
Value share of FAO crops under GTAP crop category for Brazil

Oilseed (osd)
35% of national crop value



Sugar crops (c_b)
15% of national crop value





Other grains (gro)
13% of national crop value

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