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Land-Efficient Allocation of Agricultural Production Under Alternative Trade Regimes: Implications for Global Land-Use Change and Biodiversity

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Agriculture, land use, and biodiversity

Agricultural expansion is a major pressure on terrestrial biodiversity.

- Global biodiversity is declining under increasing human pressure[1].
- Land-use change associated with agriculture is one of the major direct drivers of biodiversity loss in terrestrial ecosystems.
- At the same time, global food demand is expected to continue increasing[2].

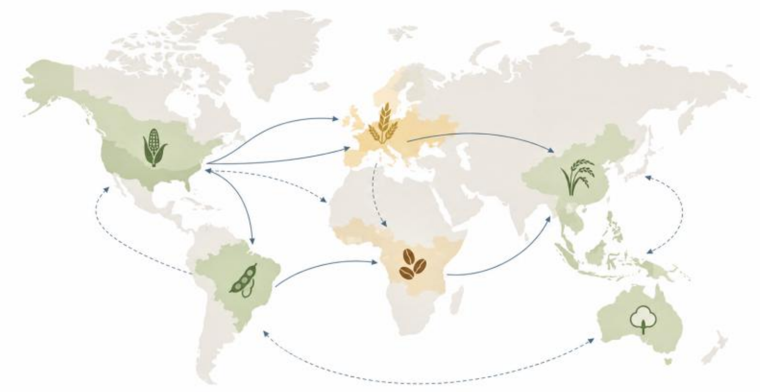
➢ Meeting future food demand while limiting agricultural land expansion is a central challenge for biodiversity conservation.

[1]IPBES (2019); [2]van Dijk et al. (2021)

Production allocation and land demand

- Agricultural land productivity differs widely across regions and commodities.

- Previous land-saving studies suggest that more efficient spatial use of cropland could substantially reduce global cropland requirements [3,4,5].
  - High-yield farming and crop allocation could reduce cropland requirements by nearly 50% while maintaining current production[4].
  - Current cropland requirements could be reduced by 37–48%, depending on the land-saving strategy[5].



[3]Mauser et al. (2015); [4]Folberth et al. (2020); [5]Schneider et al. (2022)

Trade and displaced biodiversity pressures

- Trade-footprint studies show that consumption in one region can generate biodiversity pressures in distant production regions.
- It is estimated that about 30% of global species threats were associated with international trade[1].
- 33% of biodiversity impacts in Central and Southern America and 26% in Africa were driven by consumption in other world regions in 2011[2].
- These studies highlight the importance of trade in linking consumption, production, and biodiversity impacts[3].

[6]Lenzen et al. (2012); [7]Marques et al. (2019); [8]Kastner et al. (2021)

Research gap and objective

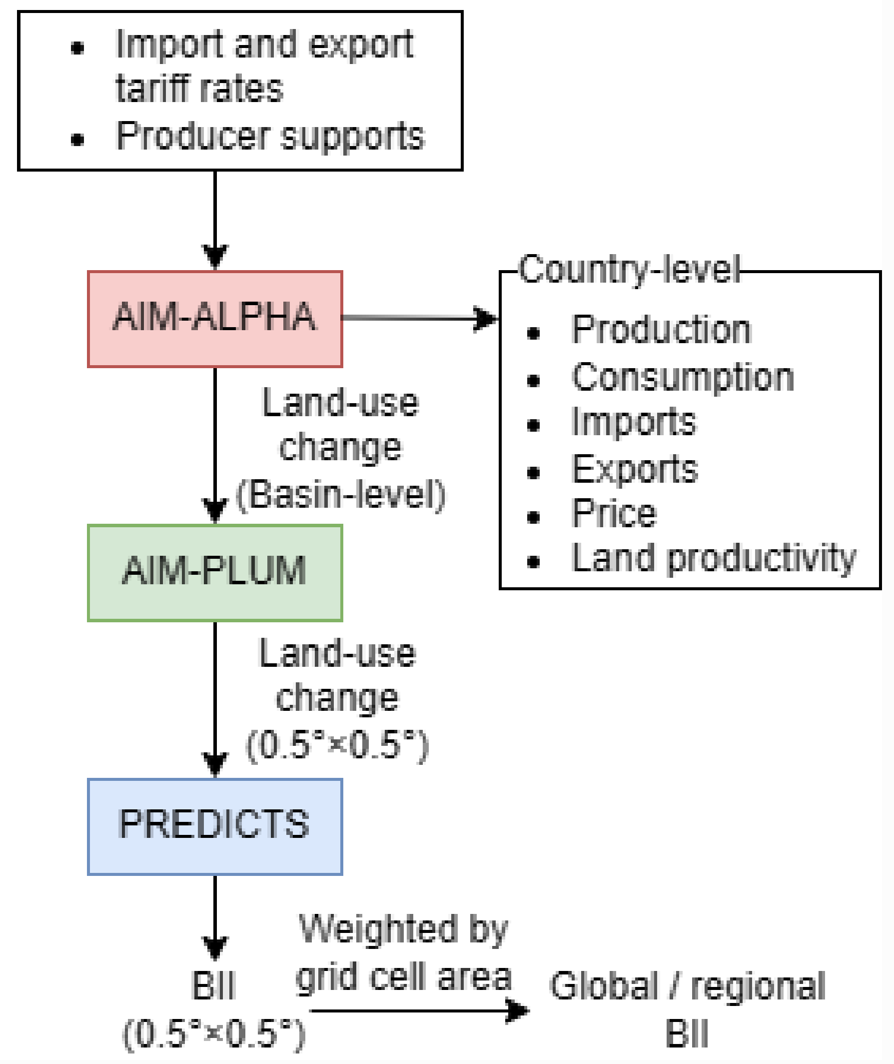
- Land-saving studies have shown that agricultural land demand depends on productivity and spatial allocation.
- Trade-footprint studies have shown that international trade can redistribute environmental pressures across regions.
- However, the role of trade-driven production allocation in future land-use and biodiversity outcomes remains insufficiently understood.

This study examines how alternative trade regimes affect agricultural production allocation, land-use change, and biodiversity.

Modeling framework

- Global agricultural partial equilibrium model **AIM-ALPHA**[9]
  - Simulates production, consumption, prices, land allocation, and trade for 166 countries.
- Land-use downscaling model **AIM-PLUM**[10]
- Biodiversity model **PREDICTS**[11]
  - Estimates biodiversity impacts from spatially explicit land-use change.
- Biodiversity Intactness Index (**BII**)

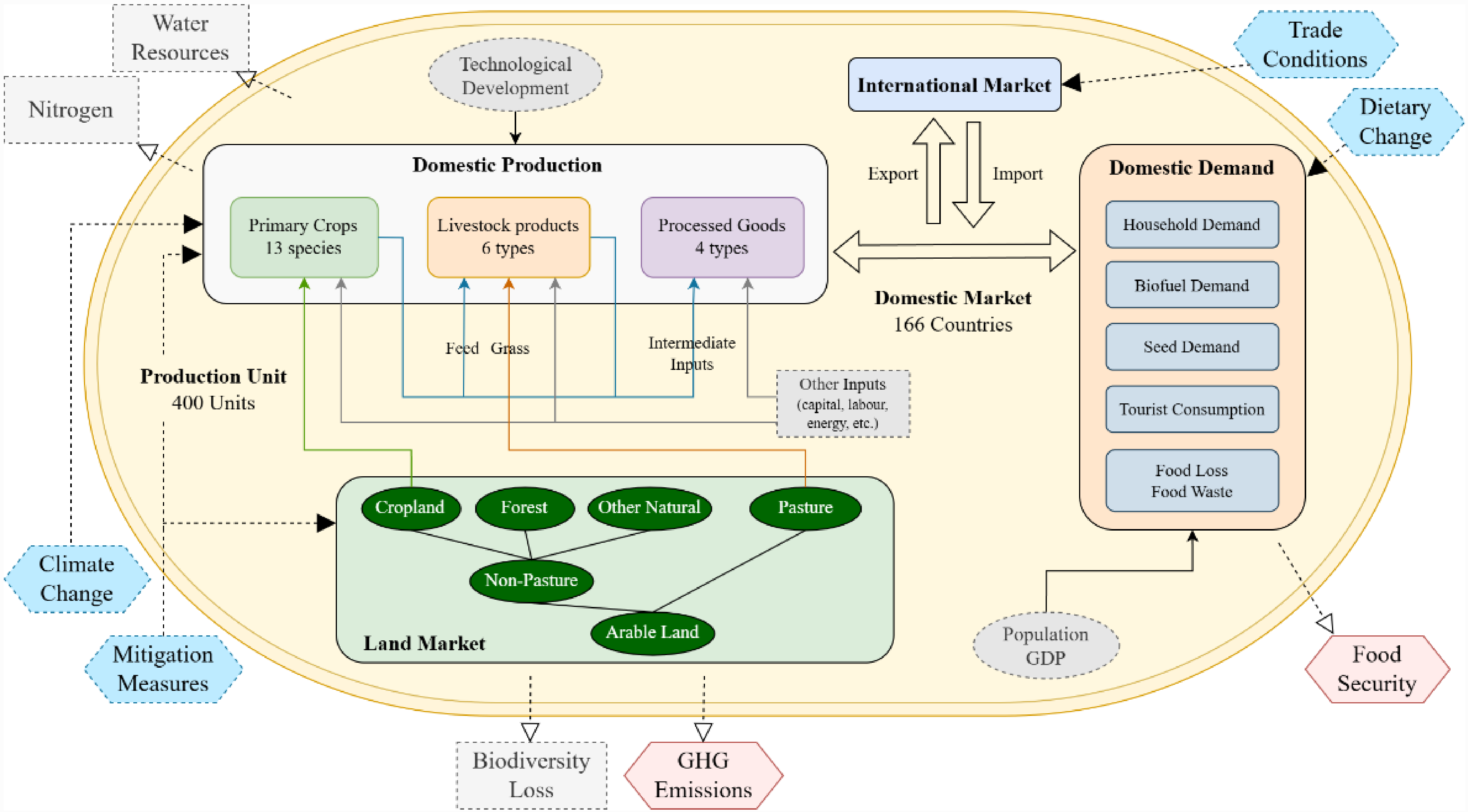
  Higher BII indicates biodiversity closer to minimally disturbed conditions.



[9]Totake et al. (2025); [10]Hasegawa et al. (2017); [11]Purvis et al. (2018)

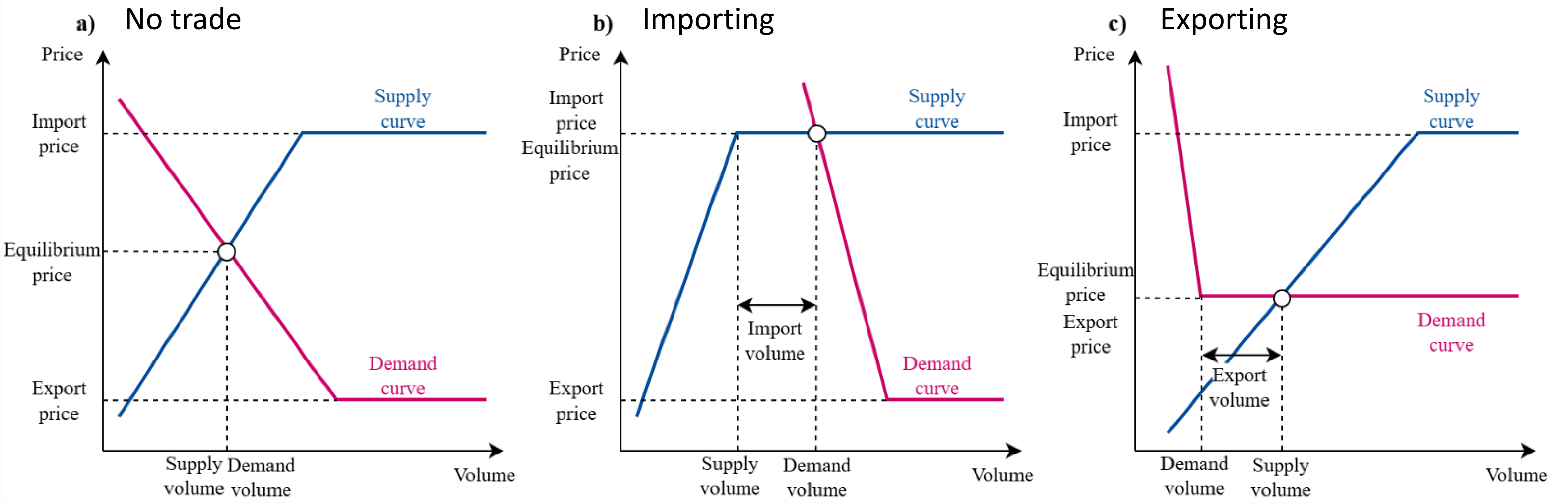
AIM-ALPHA model structure

- Recursive-dynamic partial equilibrium model of global agriculture and land use



- 166 countries for demand side
- 400 production units for production side
- 23 agricultural commodities
- Annual time step

Trade representation of AIM-ALPHA



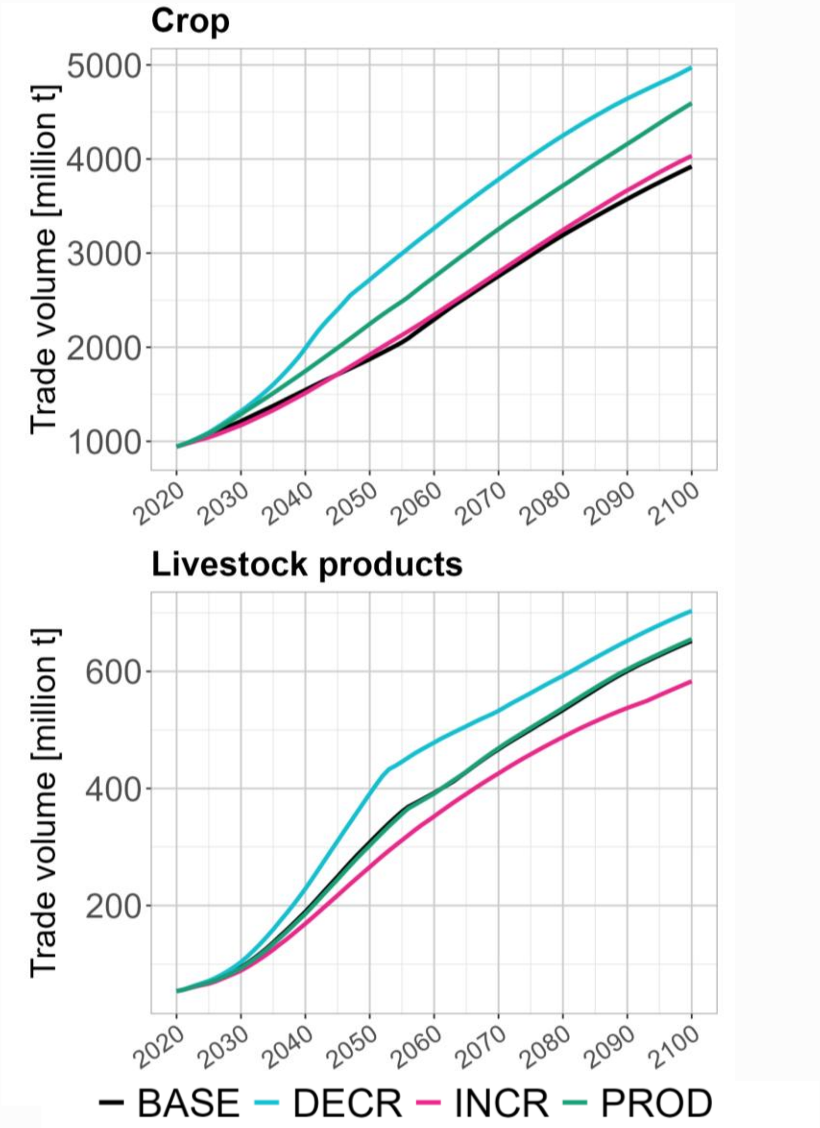
- For each country and commodity, import and export price bounds determine whether the country imports, exports, or does not trade.

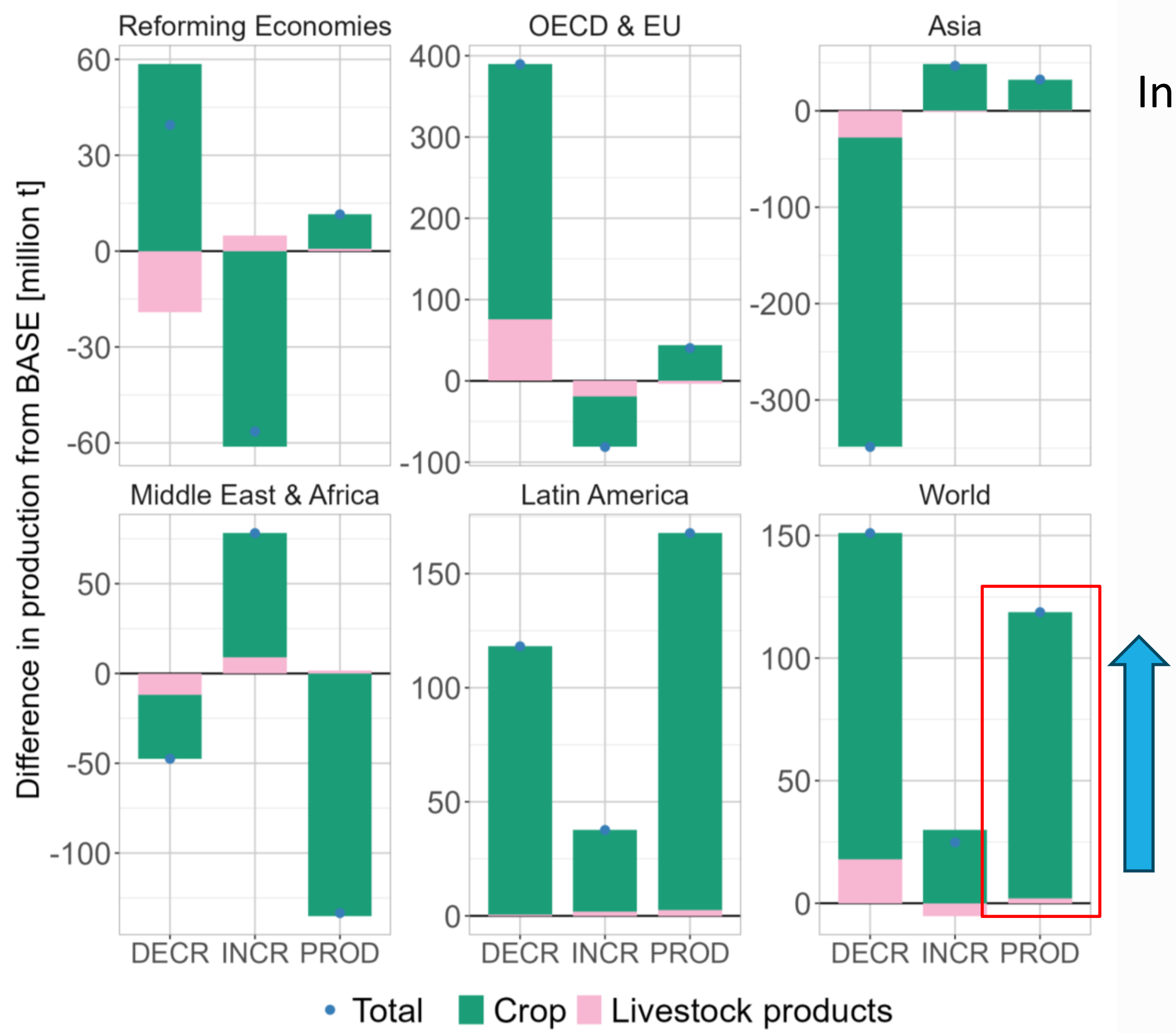
Scenario design

Scenario	Interpretation		Import Tariff	Export Tariff	Producer support
BASE	**Fixed at 2015 values**	-	Fixed at 2015 values		
DECR	**Uniform decrease in tariffs and producer support**	-	- 50 %	- 50%	- 50%
INCR	**Uniform increase in tariffs and producer support**	-	+ 50%	+ 50%	+ 50%
PROD	**Productivity-oriented scenario based on land productivity**	High-land-productivity countries than the average	+ 50%	- 50%	+ 50%
		Low-land-productivity countries than the average	- 50%	+ 50%	- 50%

- Socioeconomic drivers follow SSP2
- Simulation period: 2015–2100
- Future climate impacts on agricultural productivity are not considered

Trade regimes reshape production allocation and trade volumes

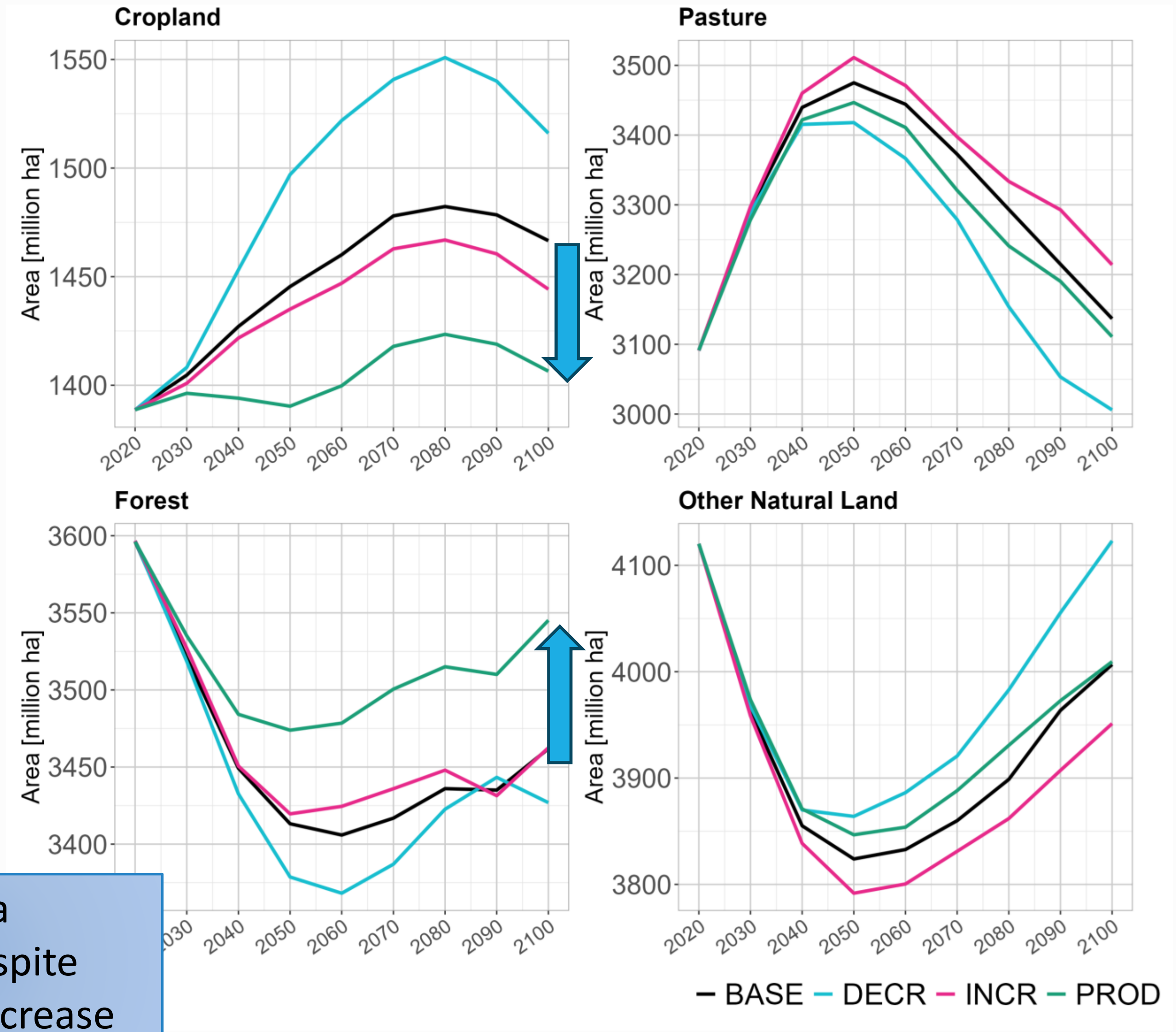


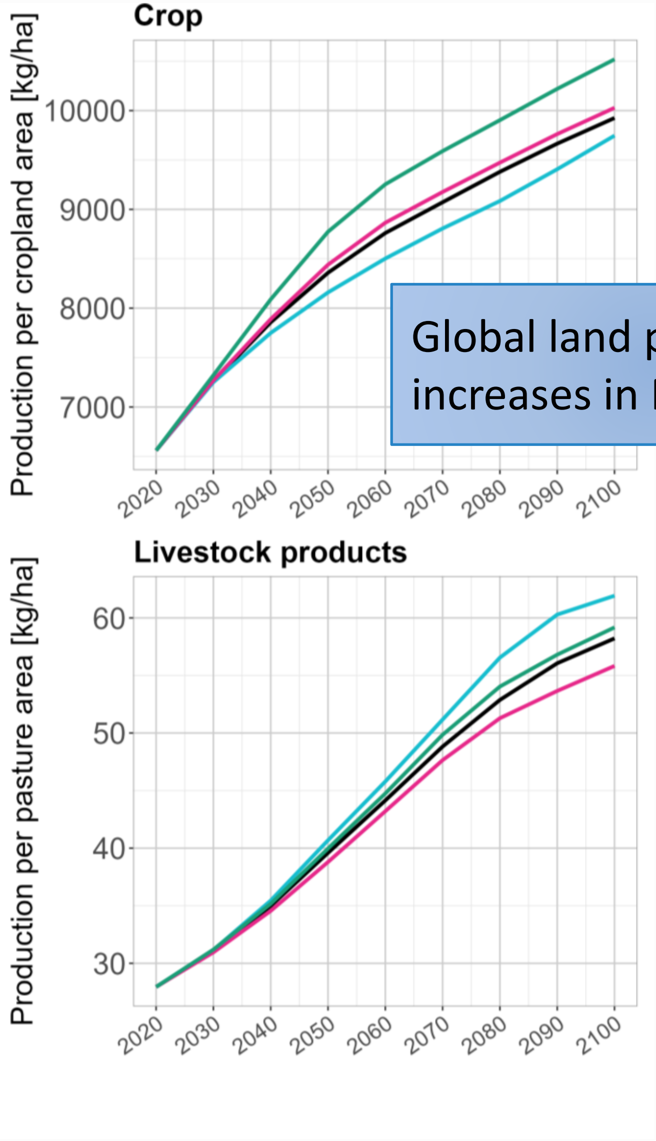


In 2100

Consumer prices of agricultural commodities in 2100

Land use change and land productivity

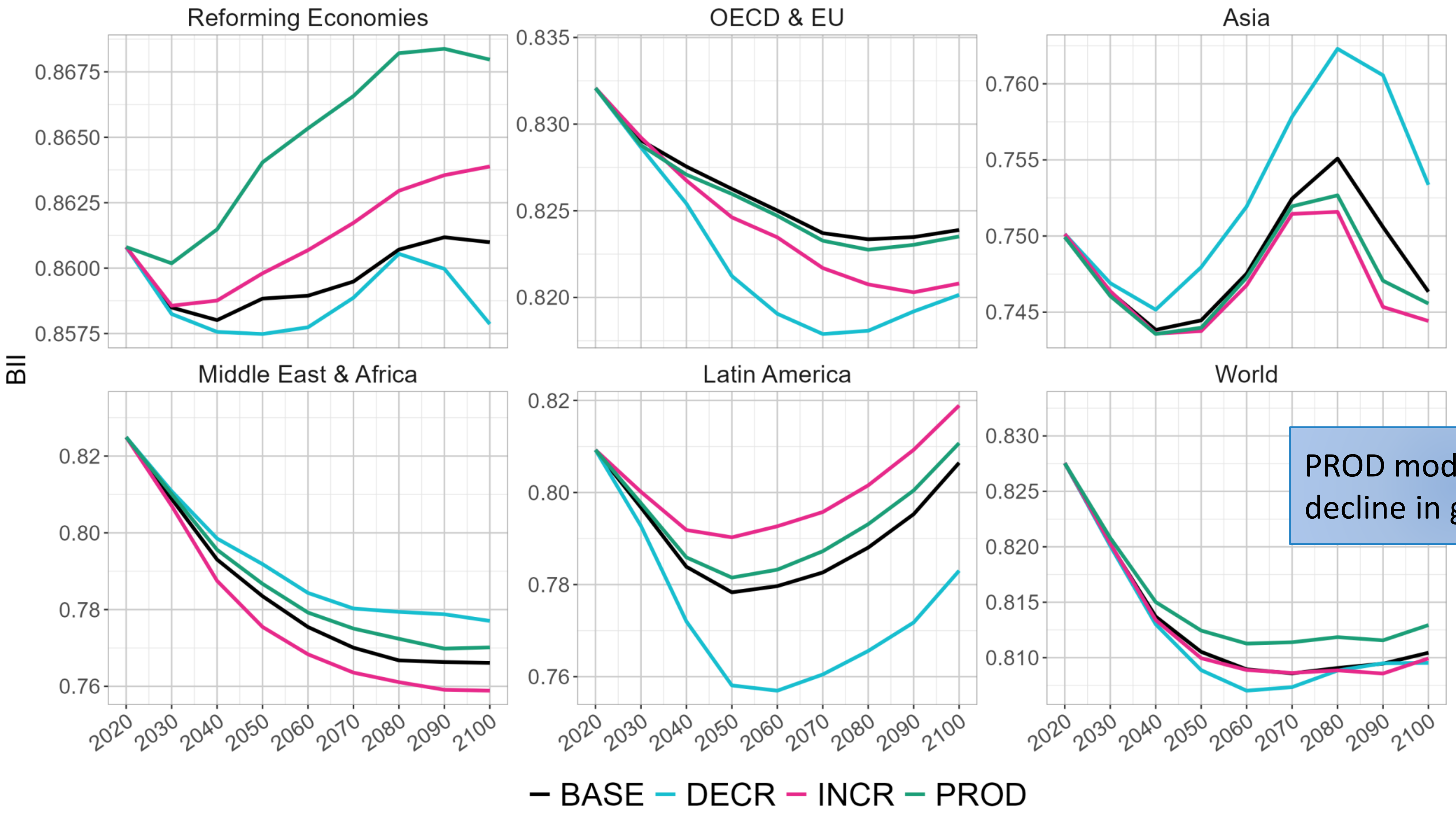




Global land productivity increases in PROD

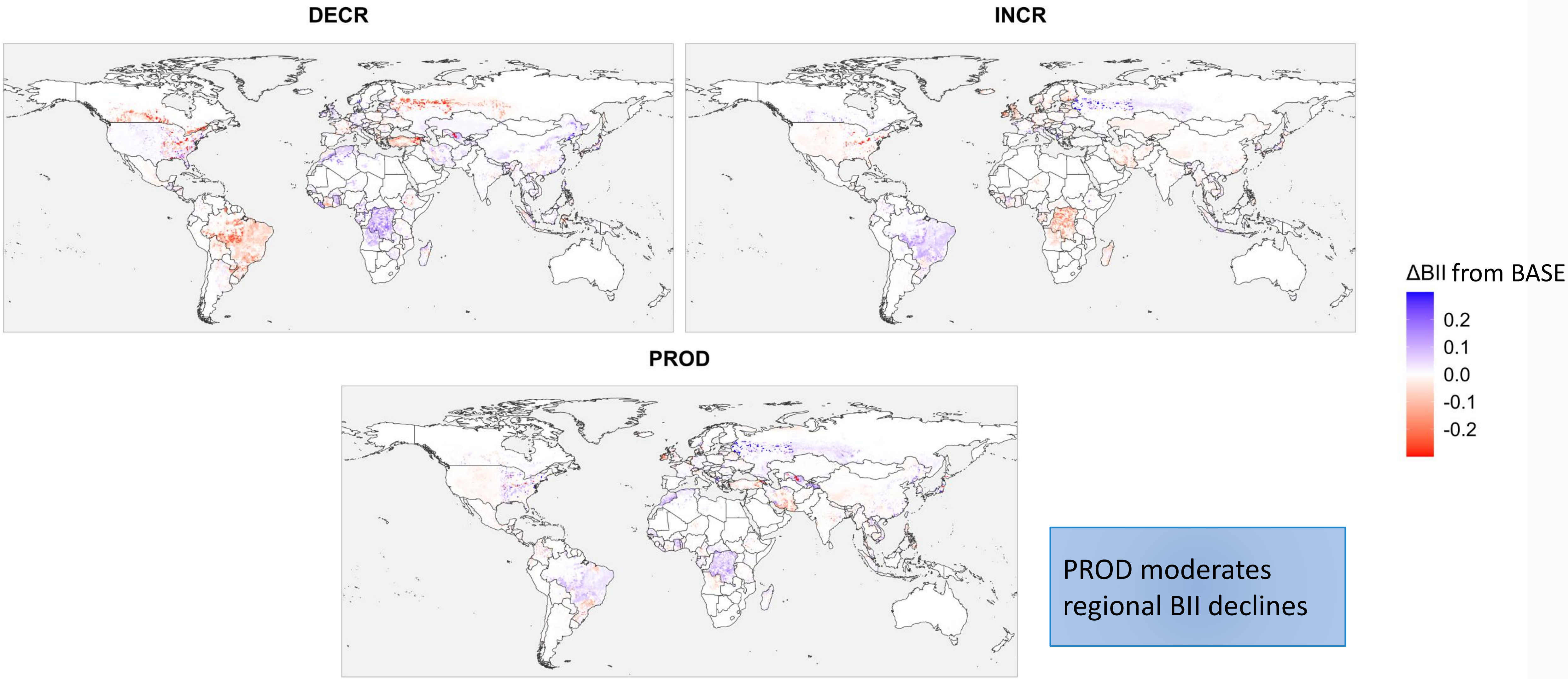
Cropland area decreases despite production increase

Biodiversity trajectories



PROD moderates the decline in global BII

Spatial distribution of biodiversity impacts in 2100



PROD moderates regional BII declines

Trade regimes affect biodiversity through the geography and land efficiency of production

Uniform changes in trade regimes did not consistently reduce land-use pressure or biodiversity loss.

- **DECR:** trade increased, but lower crop land productivity and greater cropland expansion.
- **INCR:** cropland decreased, but pasture expansion limited biodiversity benefits.
- **PROD:** production shifted toward relatively land-efficient locations, increasing average land productivity and reducing agricultural land demand.

These results suggest that the structure of trade regimes matters for land-use efficiency and biodiversity conservation.

Conclusion

- Alternative trade regimes produced different geographies of agricultural production.
- Uniform liberalization and protectionism did not consistently reduce land-use pressure or biodiversity loss.
- The productivity-oriented regime increased land productivity, reduced agricultural land demand, and alleviated biodiversity loss.

The environmental effects of trade depend not simply on trade openness, but on how trade regimes shape the geography and land efficiency of agricultural production.

Future work

- Broader economic and welfare effects
- Food security and distributional impacts
- Climate impacts on agricultural productivity
- Additional biodiversity indicators beyond BII

Thank you for your attention

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