Global-Local-Global Analysis of Systems Sustainability

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Can carbon pricing help improve water quality?

Presented by Jing Liu

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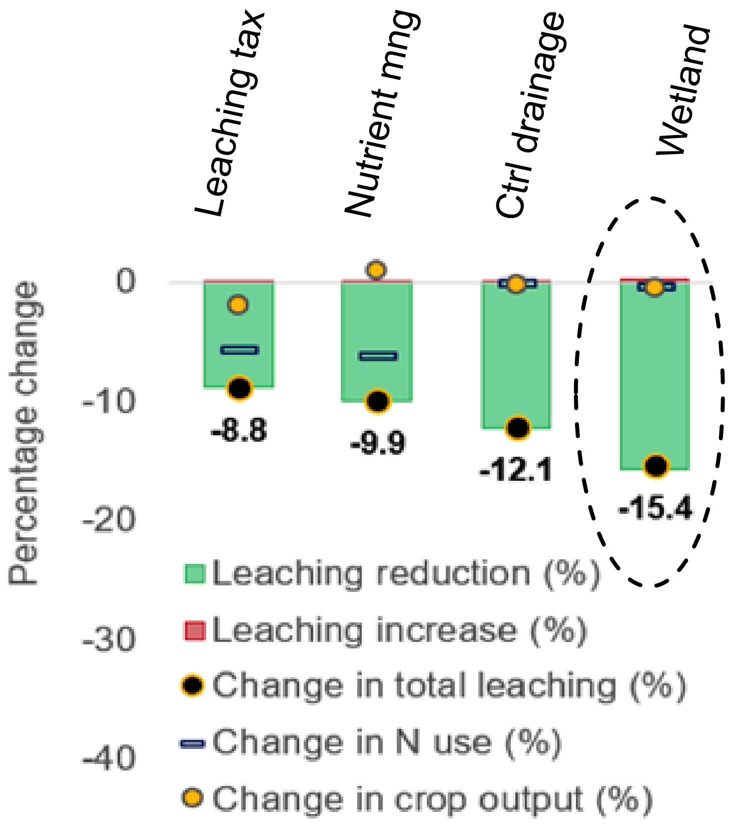
Motivated by existing studies reporting…

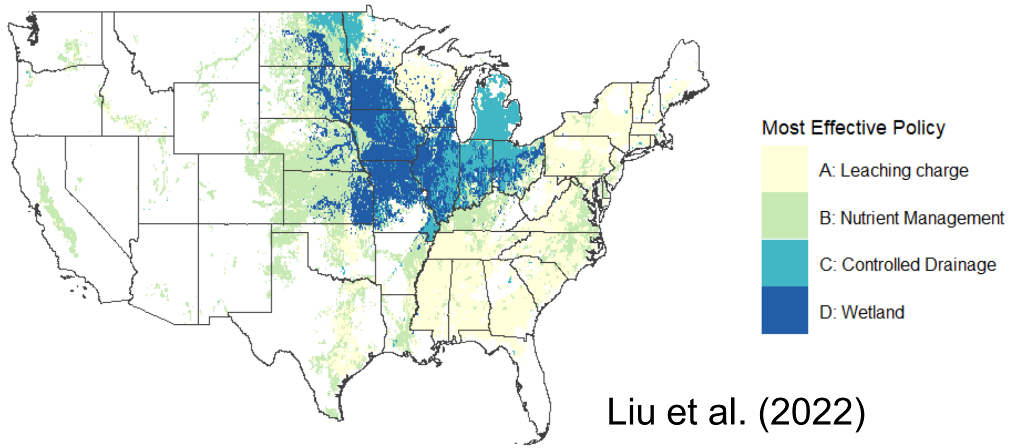
- **Co-benefits and side-effects of carbon policies**
  - Higher energy cost may impact agricultural **production costs** and **farm income**
  - Co-benefits of improving **environmental qualities** (nitrate leachate runoff and soil erosion)

- **Effectiveness of simultaneous and stand-alone climate change policies and environmental regulations** (Daigneault et al., 2018)

- **Common limitations**
  - Fixed commodity prices (Antle et al., 1999)
  - Lack of spatial details (Schneider and McCarl, 2005)
  - Ignore the spillover effect (Feng and Kling, 2005)

The ‘wicked’ hypoxia problem





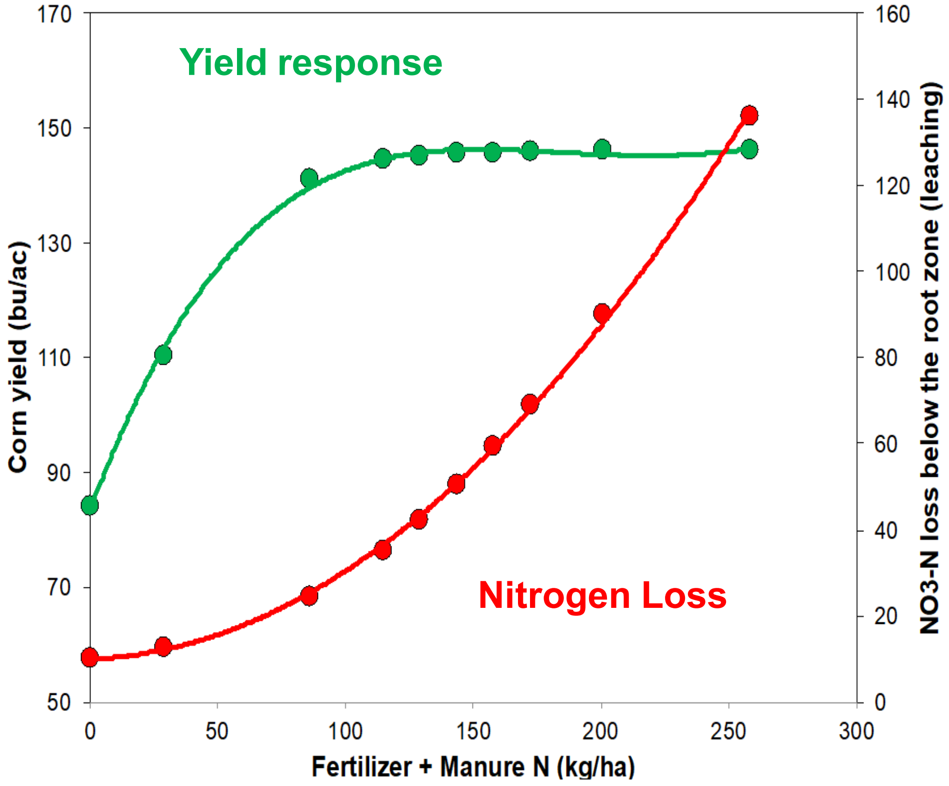
Liu et al. (2022)

- Large amounts of nitrate lost from soils in the Corn Belt created ‘dead zones’ (hypoxia) in the Gulf of Mexico
- No silver bullet can achieve the Hypoxia Task Force Goal of reducing N load to the Gulf by 45% by 2035
- Wetland alone can reduce N load by 15% and up to 30% if combined with other conservation practices, but still cannot make the HTFG
- ***Does carbon policy have the dual benefits of reducing GHG emissions and improving water quality? How effective compared with conservation policies?***

Economic model with biophysical features

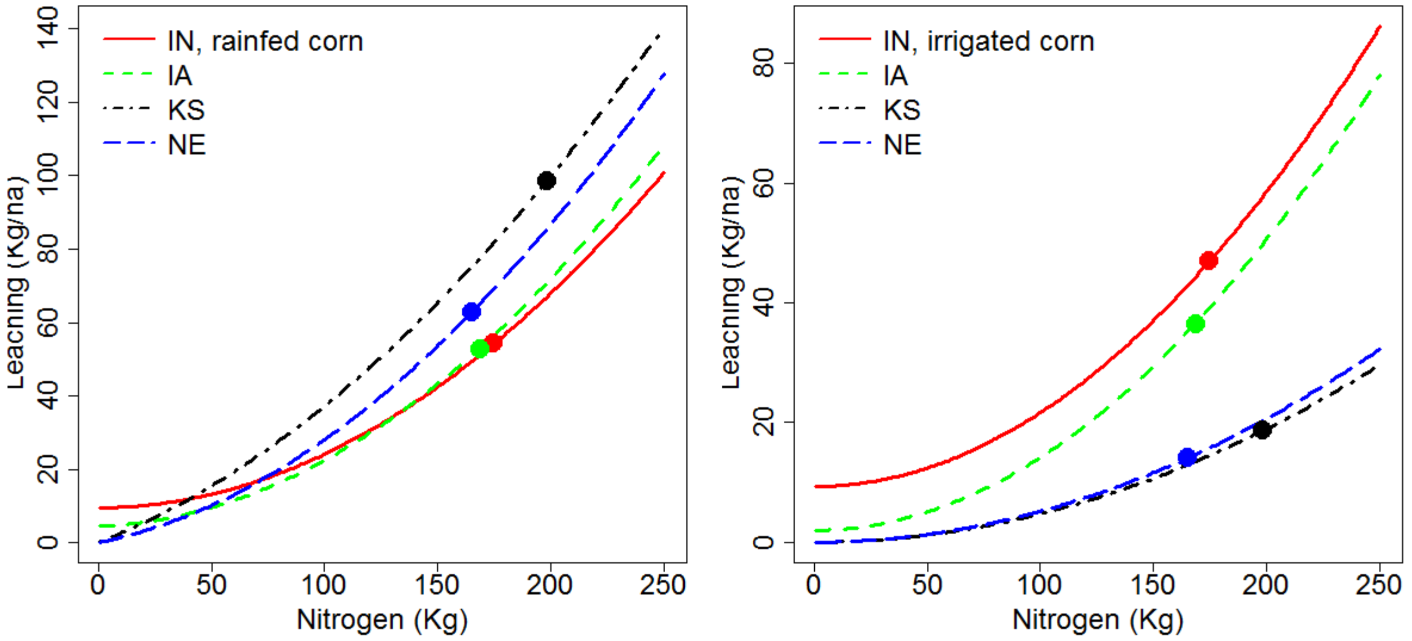
- **SIMPLE-G-US-CS model**
  - Global partial equilibrium model with gridded input & output
  - 48,317 five-arcmin pixels in the US + 16 non-US regions
  - Corn and soy cropland area only

- **Embedded yield and nitrate leaching response to N fertilizer use**
  - Estimated based on a process-based agro-ecosystem model Agro-IBIS
  - Vary by grid and by irrigated and rainfed activities



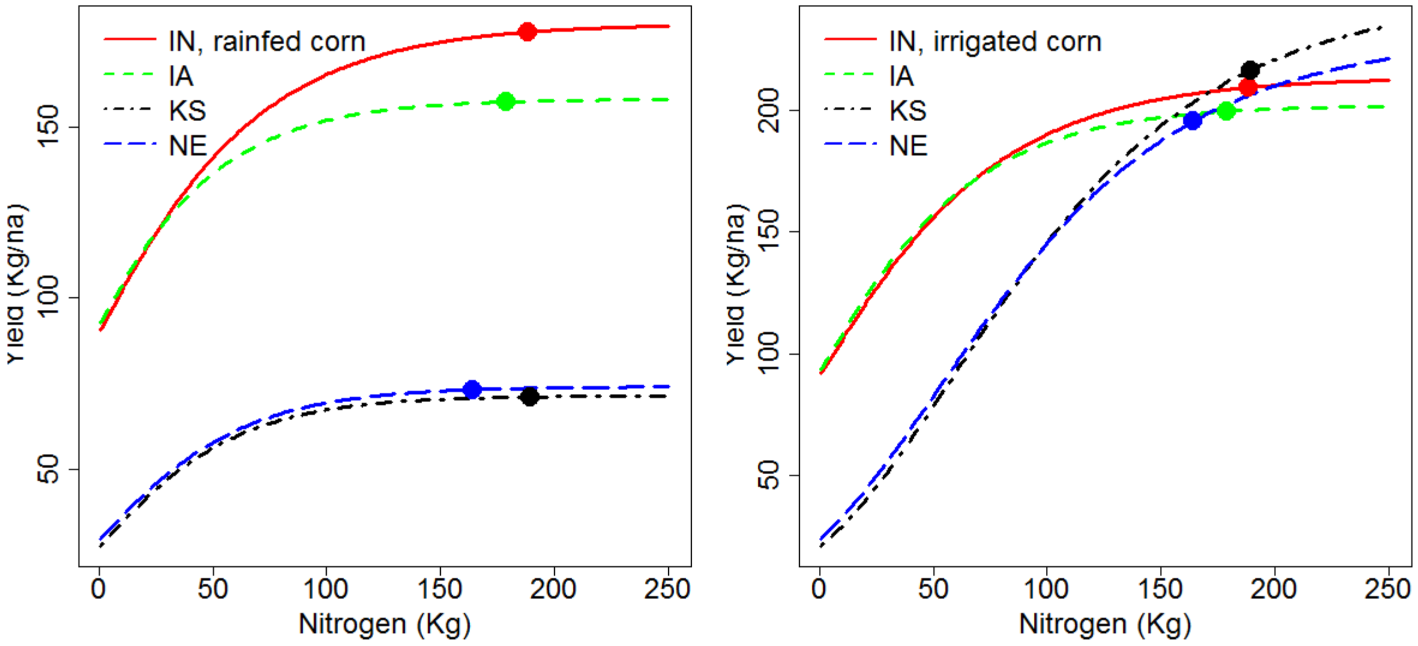
Leaching emulator

$$L(N) = a + bN + cN^2$$



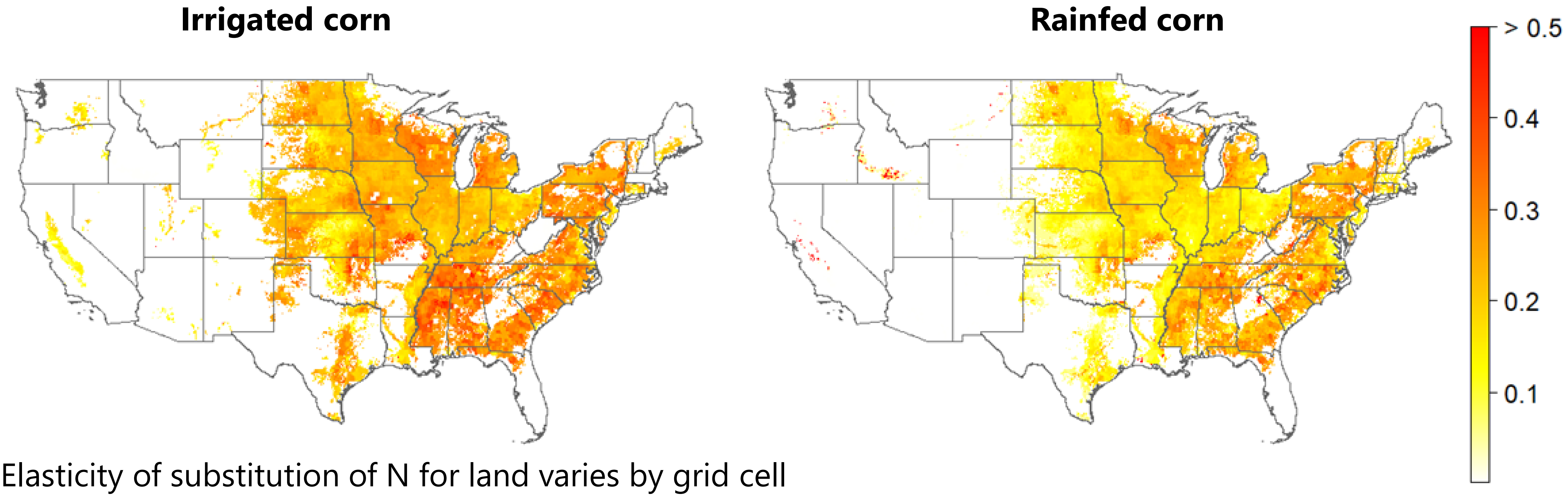
Yield emulator

$$f(N) = a \times \exp(-b \times c^N)$$



Substitutability between land and fertilizer estimated from the Gompertz function

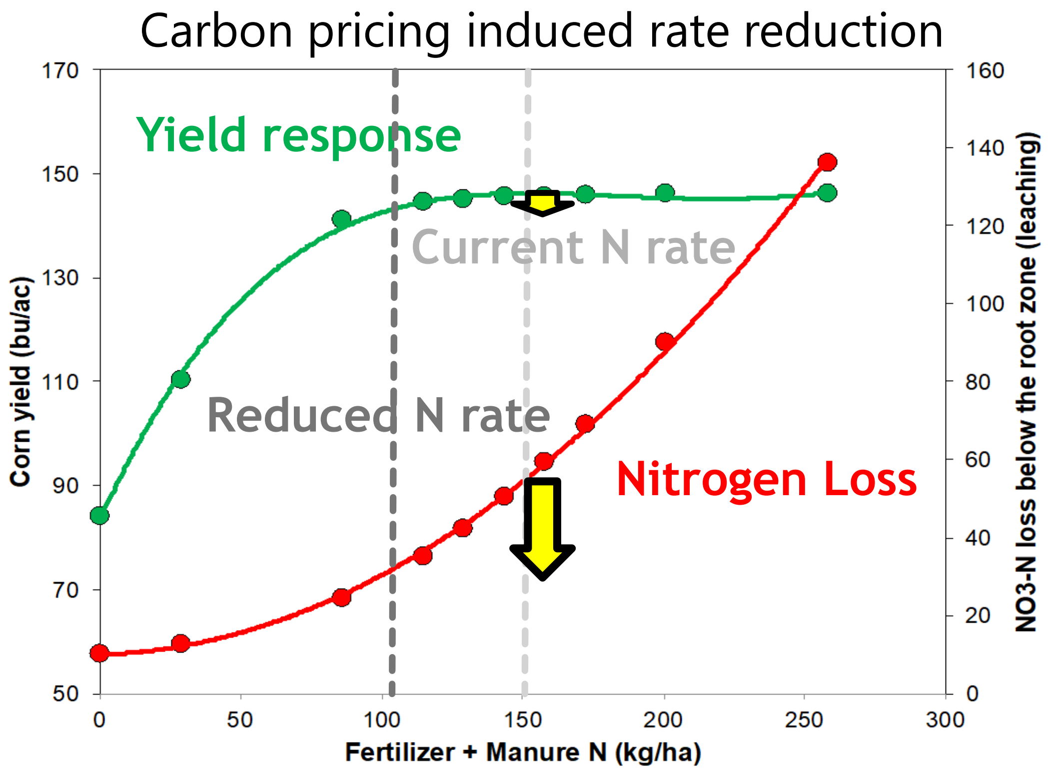
$$\sigma_{LN} = \frac{f'(n)[f(n) - nf'(n)]}{-nf''(n)f(n)}$$

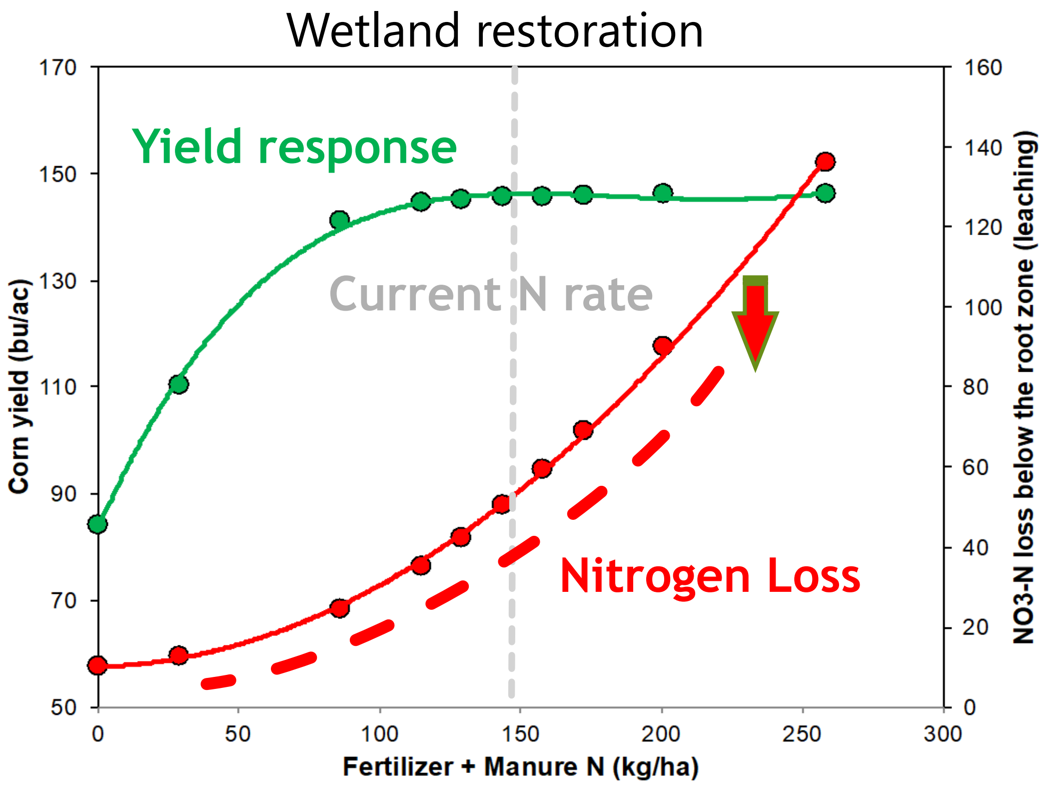


Elasticity of substitution of N for land varies by grid cell

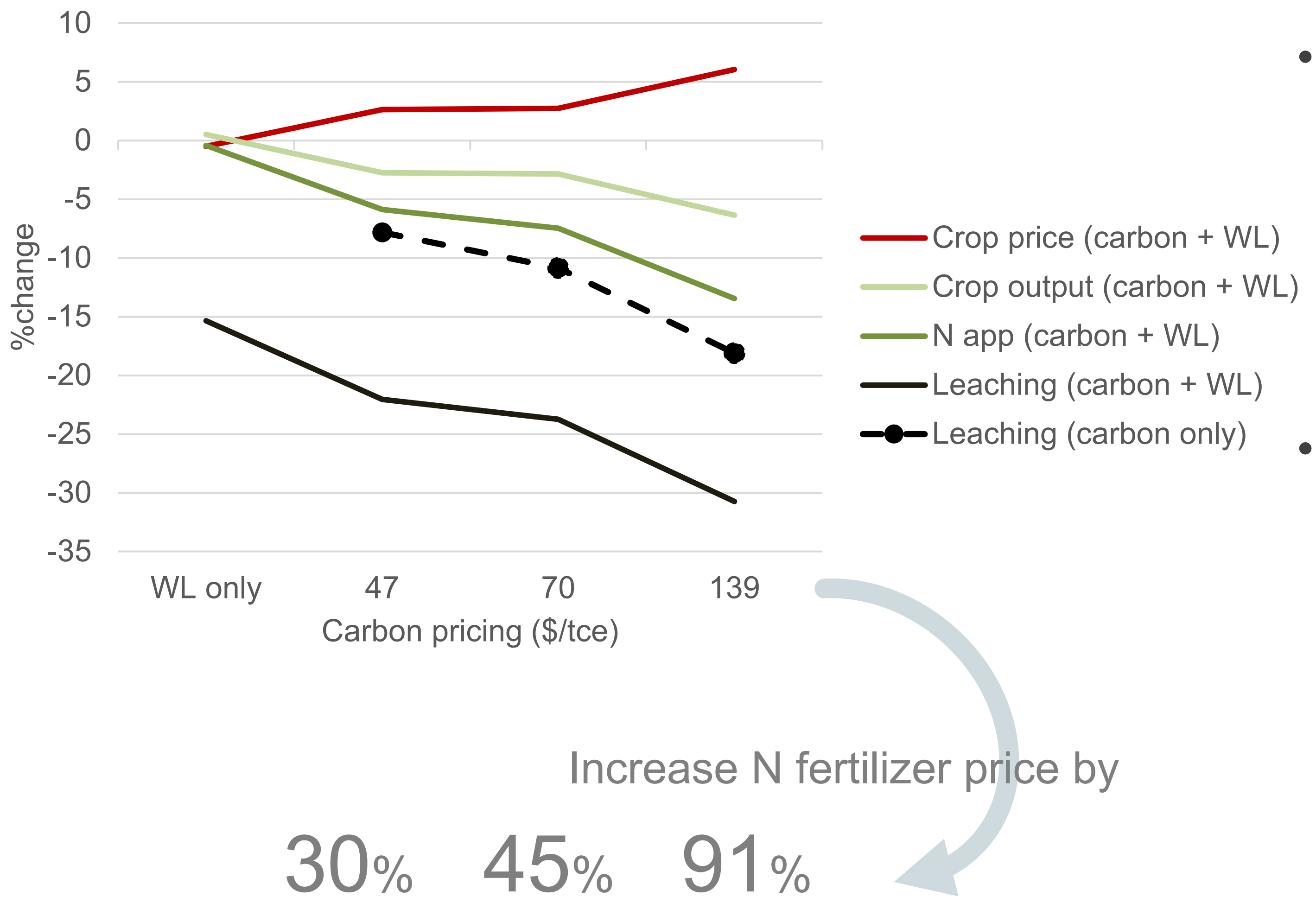
Experiments

- **Carbon pricing only** (Various carbon pricing at $47, $70 and $139 / tce)
- **Carbon price & wetland restoration combined**



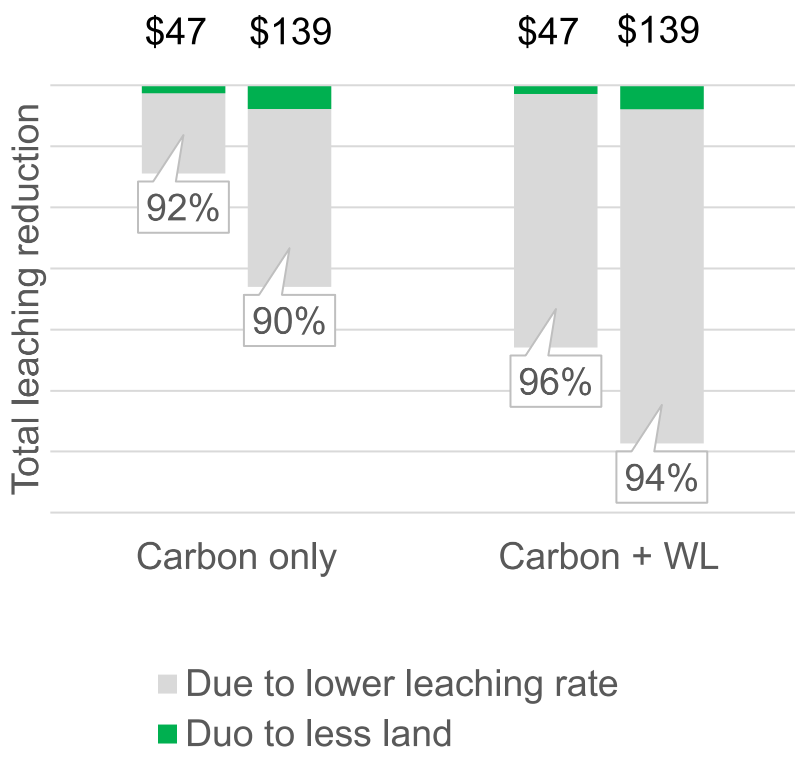


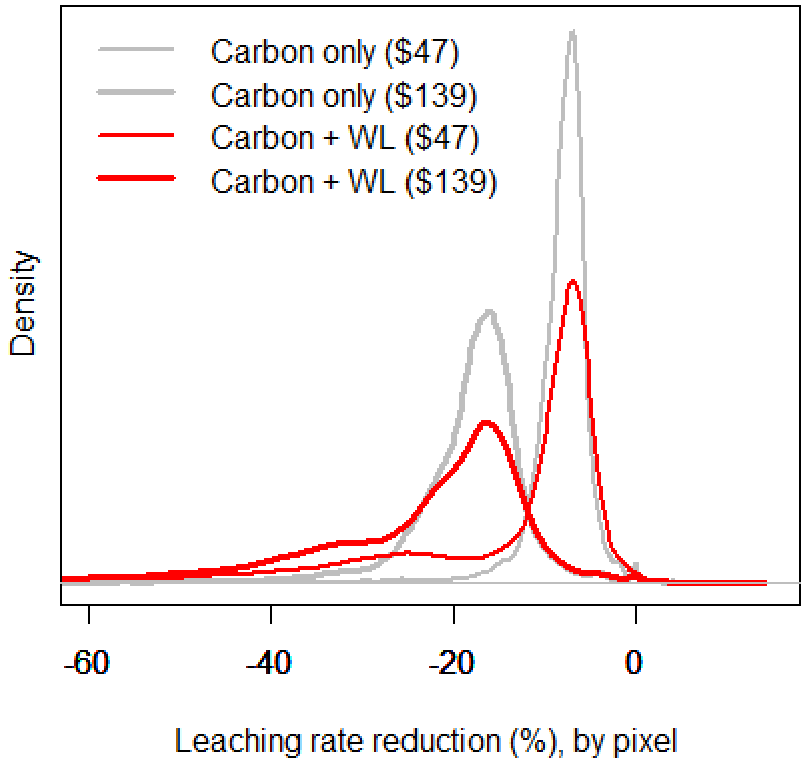
Combined policies have much larger impacts on N application and crop production than wetland alone



- A carbon pricing of $139 / tce
  - nearly doubles the price of N fertilizer
  - leads to more leaching mitigation (-18%) than wetland alone (-15%)
- Higher N fertilizer cost puts pressure on food price
  - N application -6%~ -13%
  - Crop output -3% ~ -6%
  - Crop price +3% ~ +6%

Mitigation is attributed more to lower leaching rate than less cropland

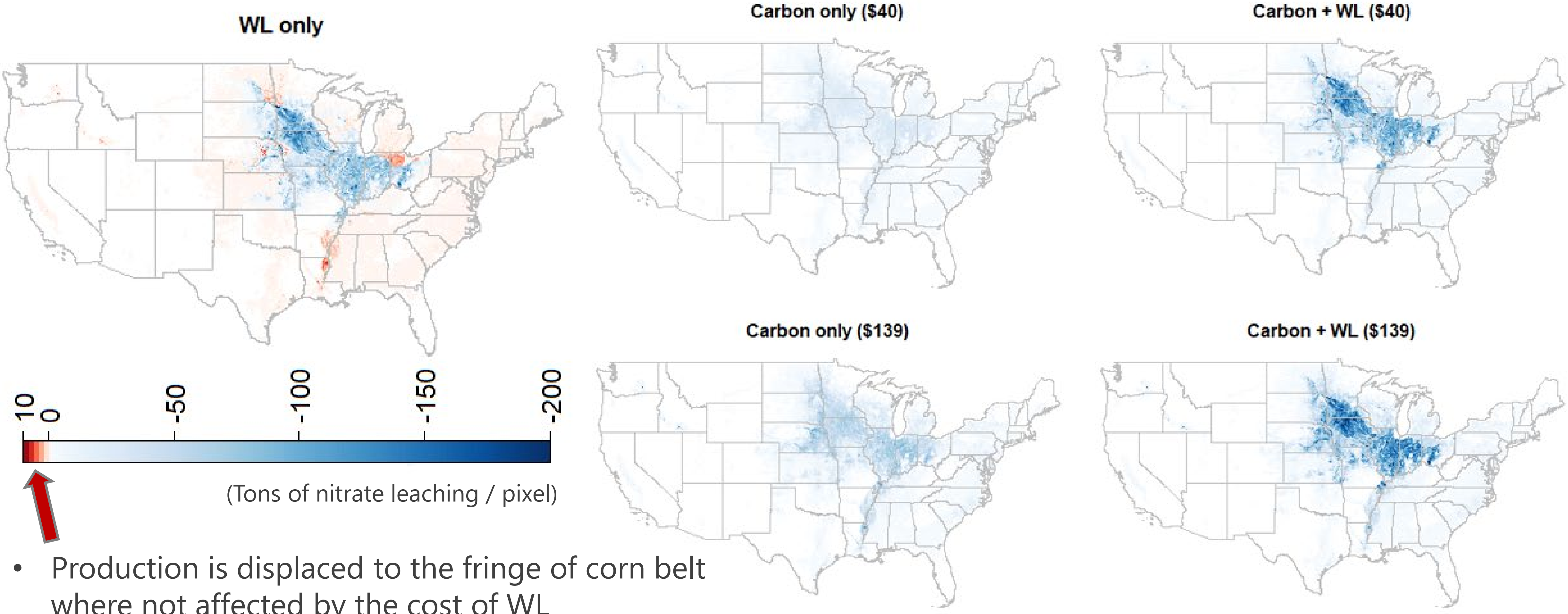




- Over 90% of the mitigation is contributed by lower leaching rate (kg of leaching /ha)
- Even higher under combined policies due to the greater effectiveness of wetland

- Leaching rates reduce more at higher carbon pricing & exhibit larger variance due to the spatially varied mitigation effect of wetlands

Combined policies impede the spatial spillover effect caused by site-specific conservation practices



- Production is displaced to the fringe of corn belt where not affected by the cost of WL
- The comparative advantage disappears with the presence of carbon pricing

Summary

- **Main findings**
  - Achieving the **HTFG may not be impossible** if combine policies instruments
  - Mitigation outcomes result more from the **intensive** than the extensive margin
  - Simultaneous climate and conservation policies can **overcome the unintended effects** created outside the scope of the stand-alone policy

- **Next step …**
  - **Yield** impacts of combined policies
    - What carbon pricing delivers economically and environmentally optimal N application rate?
  - Benefits of **coordinating** carbon sequestration and conservation programs
    - Carbon tax revenue allocation; ownership of externality
  - **Uncertainties** associated with behaviors and biophysical process