Effects of agricultural intensification on regional climate: Looking at climate change from the ground up

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Twentieth Century Regional Climate Change During the Summer in the Central United States Attributed to Agricultural Intensification

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The United States’s Corn Belt is making its own weather
Outline

• Global picture
• Research questions
• Agricultural intensification and regional climate
  • Background
  • Observational trends
  • Numerical modeling methodology
  • Modeling results
  • Proposed mechanisms
  • Conclusions and implications
• Take-home messages
Global picture
Global anthropogenic CO₂ emissions

Quantitative information of CH₄ and N₂O emission time series from 1850 to 1970 is limited.

- Fossil fuels, cement and flaring
- Forestry and other land use

IPCC, 2013
Global Mean Estimates based on Land and Ocean Data

Temperature Anomaly (°C)

- Annual Mean
- Lowess Smoothing

Atmospheric CO₂ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

NASA GISS

NASA GISS, 2017

Temperature [°C]

Alter et al., 2018

Precipitation [mm day\(^{-1}\)]

Alter et al., 2018

-0.75 -0.6 -0.45 -0.3 -0.15 0 0.15 0.3 0.45 0.6 0.75
Central US vs. Northern mid-latitudes
Pielke et al., 2011 (adapted)

Cropland + Pastureland
Crop Yield

Ray et al., 2012
Agricultural Intensity

Mueller et al., 2016
Research questions

• What are the impacts of agricultural intensification on regional climate in the central US?

  • How do the temporal and spatial aspects of agricultural intensification compare to the historical rainfall and temperature records?

  • Which forcing has been more influential on observed regional climate change: agricultural intensification or greenhouse gas (GHG) emissions?

  • What are the potential mechanisms that lead from agricultural intensification to rainfall and temperature change?
Connection to the atmosphere

• Established links between:
  • Vegetation,
  • Soil moisture,
  • Evapotranspiration (ET),
  • Temperature, and
  • Precipitation

• Especially during summer
  • e.g., Koster et al. 2004, Betts 2004, Findell and Eltahir 2003 a,b

Koster et al., 2004
Cropland area

Irrigated area

Net primary productivity

Mueller et al., 2016
Temporal changes
Increases in crop productivity
Numerical modeling methodology

- Simulations using the MIT regional climate model – MRCM

- Five 30-year simulations from 1982 to 2011 (150 total years)
  - 30-km horizontal grid increments

- Irrigated grid cells wetted to relative field capacity after hitting 75% of RFC (July to September)

- Photosynthesis increased by factor of six in experimental simulations

Alter et al., 2018
Modeling results

GHG and other forcings

Agricultural intensification

Consistency of changes

Alter et al., 2018
GHG and other forcings

Agricultural intensification

Temperature

Specific humidity

Alter et al., 2018
Sea surface temperature

PDO index [unitless] and Corn Belt precipitation [cm] anomalies

Alter et al., 2018
Proposed Mechanisms

• Increase in photosynthesis -> increase in stomatal conductance -> increase in transpiration
  • Increase in humidity and latent heat flux
  • Decrease in temperature and sensible heat flux

• Mechanism 1
  • Increase in moist static energy (MSE)

\[
\text{MSE} = C_p T + gz + L_v r,
\]

where
- \( C_p \) specific heat of air at constant pressure (kJ kg\(^{-1}\) K\(^{-1}\)),
- \( T \) air temperature (K),
- \( g \) gravitational acceleration (m s\(^{-2}\)),
- \( z \) height above some reference level (m),
- \( L_v \) latent heat of vaporization for water (kJ kg\(^{-1}\)), and
- \( r \) water vapor mixing ratio (kg kg\(^{-1}\)).

• Mechanism 2
  • Moisture recycling
    • Moisture transpired from crops falls out as precipitation in remote areas

Alter et al., 2018
Summary of changes

<table>
<thead>
<tr>
<th></th>
<th>Sign of observed change</th>
<th>Sign of predicted change</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Agricultural intensification</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Positive$^{1,2}$</td>
<td>Positive$^3$</td>
</tr>
<tr>
<td>Surface temperature</td>
<td>Negative$^{1,2,3}$</td>
<td>Negative$^{3,4}$</td>
</tr>
<tr>
<td>Surface humidity</td>
<td>Positive$^2$</td>
<td>Positive$^4$</td>
</tr>
</tbody>
</table>
Conclusions and Implications

• **Both simulations and observations indicate cooler temperatures and enhanced rainfall during the summer in the central US due to agricultural intensification**
  • Agricultural intensification > GHG emissions for summer climate change in central US
    • However, cooling due to agricultural intensification may have masked GHG-induced warming
  • Similar climatic effects in other world regions?
  • May have enabled further agricultural intensification by filling soil moisture deficits

• Encourages the *inclusion of crop productivity in next-generation climate models and predictions*

• Adds *complexity* to existing framework of hydrological, agricultural, and economic sustainability
Take-home messages

• **Agricultural intensification**
  
  • ...has **cooled temperatures** and **enhanced rainfall** in the central US
  
  • ...has been a **stronger forcing of observed summer climate change** in the central US than increasing GHG emissions
  
  • ...and its climatic effects deserve **inclusion in future climate models and attribution studies**
  
  • ...warrants future **consideration in plans to adapt to and mitigate climate change around the world**
Thank you!

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