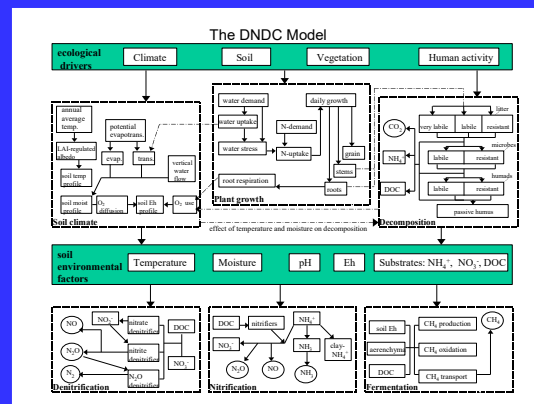


Nonlinear and Divergent Responses of Crop Yield and Soil Nitrous Oxide Emissions to Precipitation Changes: A Modeling Approach



Dafeng Hui, Ph.D.

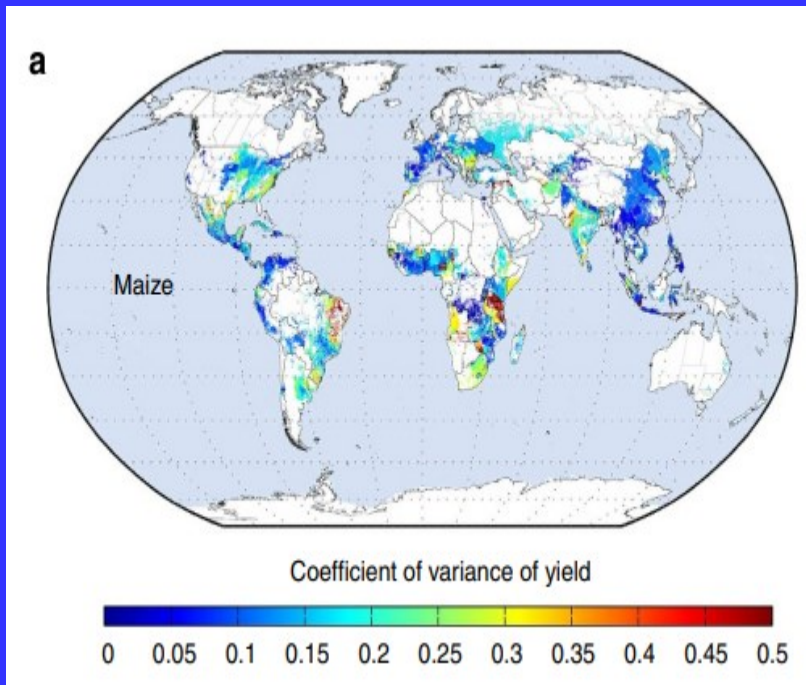
J. Christian, A. Chauvin, H. Hayat, R. Thapa, Y. Chen

Tennessee State University, USA

N. Girkin, Uni. Of Nottingham, UK; D. Ricciuto, M.A. Mayes, Oak Ridge National Laboratory, USA; H. Tian, Boston College, USA



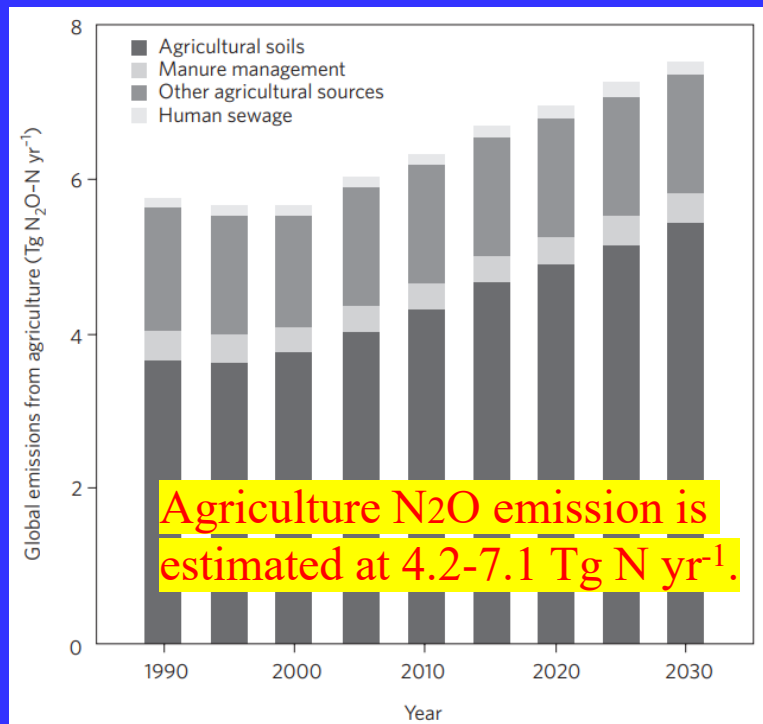
Improving Crop Yield and Stability: A Key Challenge for Food Security



Ray et al. 2014, *Nature Communication*
Rezaei et al. 2023, *Nature Review Earth and Environment*

- Variability in crop yields poses a major challenge to global food security.
- This variability is driven by fluctuations in temperature and precipitation, which are expected to intensify in the future.
- Globally, climate variability accounts for roughly a third of the observed yield variability.

Soil N₂O Emissions Are Regulated by Precipitation

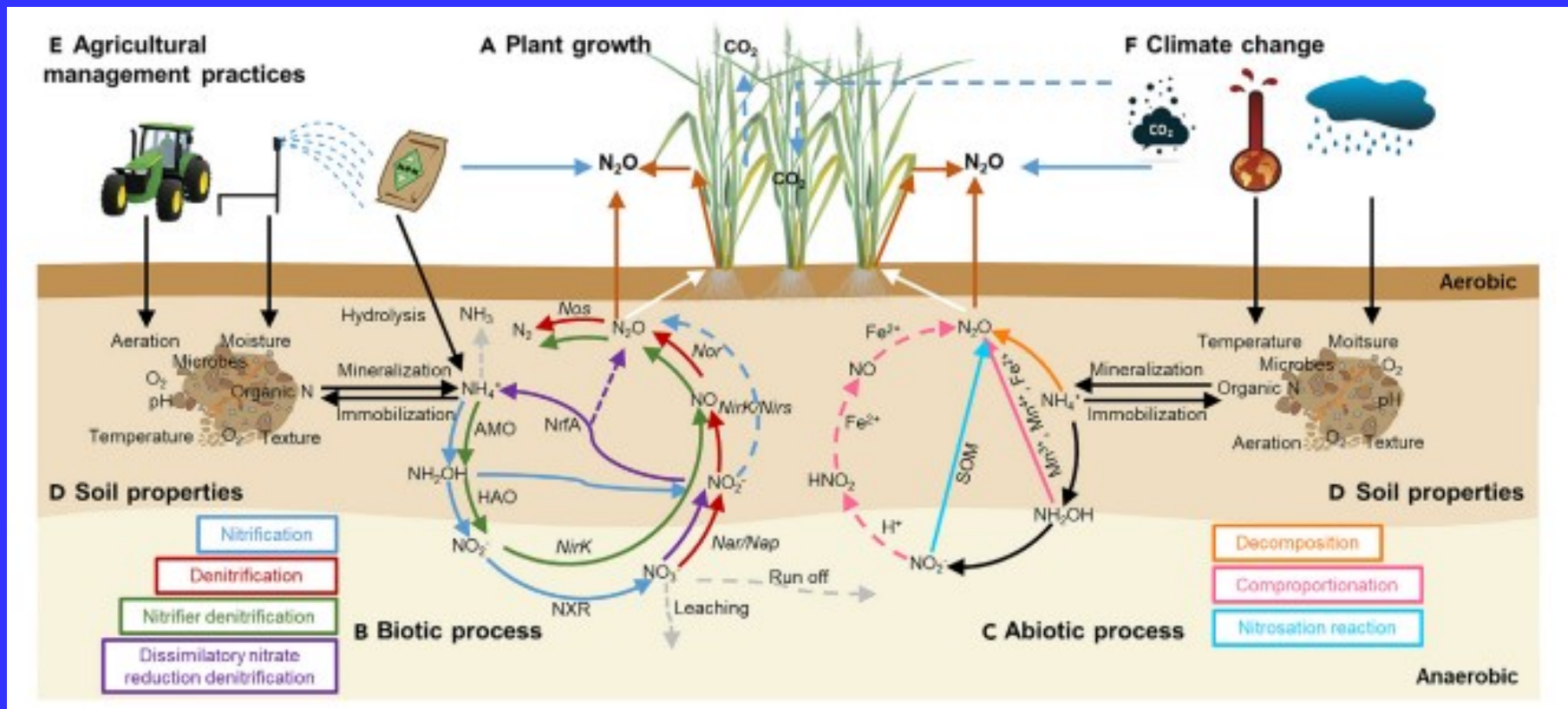


Reay et al. 2012 Nature Climate Change

Tian et al. 2020. Nature

- Agricultural practices, including nitrogen application, interact with climate to affect both yield stability and environmental outcomes (i.e., soil N₂O emissions).
- Understanding the effects of climate change and the N application is essential for sustainable crop production.

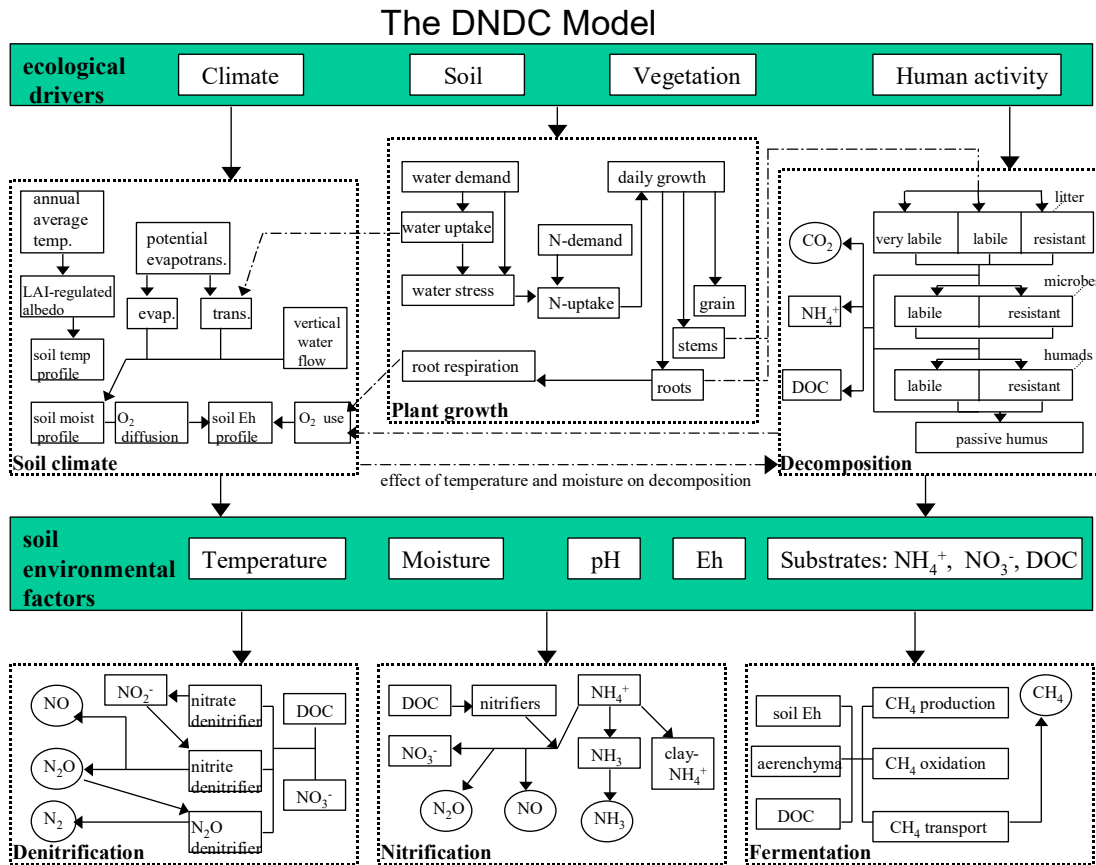
Factors Influencing Crop Yield and Soil N₂O Emissions



Objectives

1. Quantify long-term interannual variability in crop yields and soil N₂O emissions in a corn field
2. Investigate precipitation changes (i.e., droughts and precipitation increases) on crop yield and soil N₂O emissions
3. Explore relationships between yield, soil N₂O emissions and precipitation within and among different precipitation treatments

Biogeochemical Model: DNDC



DNDC: De-Nitrification De-Composition.

Li et al. (1992; 2000)

This model has been widely used in different plant types and under different climatic conditions around the world. [Http://www.dndc.sr.unh.edu](http://www.dndc.sr.unh.edu).

DNDC Modeling Studies

Journal of Geophysical Research: Biogeosciences

RESEARCH ARTICLE

10.1002/2015JG003239

Key Points:

The DNDC model is applied to simulate N₂O emission under various agricultural management practices
Modeled N₂O emission is increased by

Assessing the impacts of tillage and fertilization management on nitrous oxide emissions in a cornfield using the DNDC model

Qi Deng¹, Dafeng Hui¹, Junming Wang², Chih-Li Yu¹, Changsheng Li^{3,4}, K. Chandra Reddy⁵, and Sam Dennis⁵

Nutr Cycl Agroecosyst (2021) 120:363–378
<https://doi.org/10.1007/s10705-021-10155-4>



ORIGINAL ARTICLE

Precipitation and nitrogen application stimulate soil nitrous oxide emission

Huiling Zhang · Qi Deng · Christopher W. Schadt · Melanie A. Mayes ·
Deqiang Zhang · Dafeng Hui

Kaur et al. *Ecological Processes* (2023) 12:17
<https://doi.org/10.1186/s13717-023-00429-w>

Ecological Processes

RESEARCH

Open Access

Response patterns of simulated corn yield and soil nitrous oxide emission to precipitation change



Navneet Kaur¹, Dafeng Hui^{1*} , Daniel M. Ricciuto², Melanie A. Mayes² and Hanqin Tian³

Interannual Variability and Legacy Effects

Interannual variability (CV):

Yield: 9.87

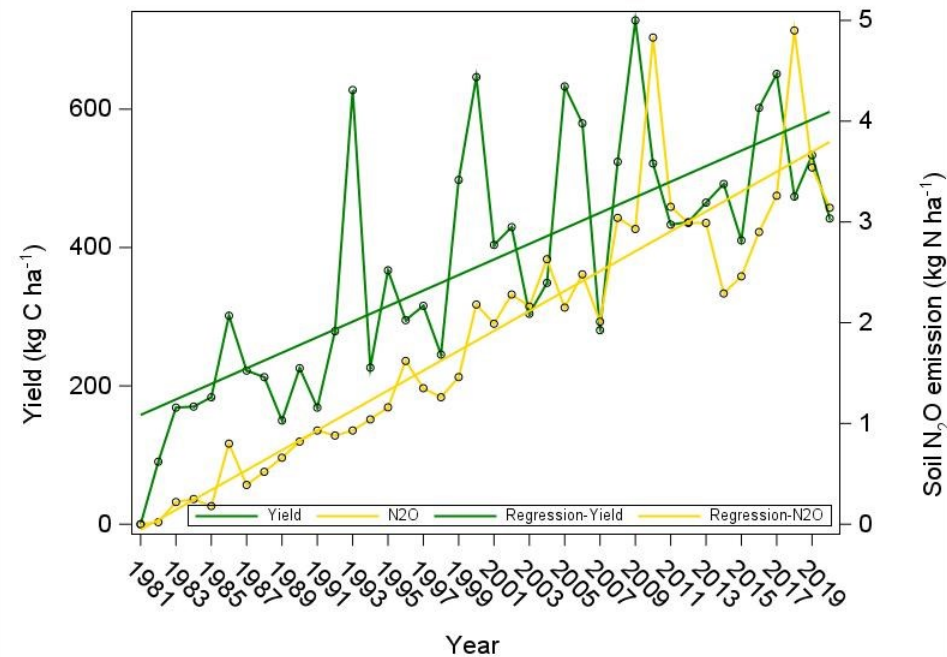
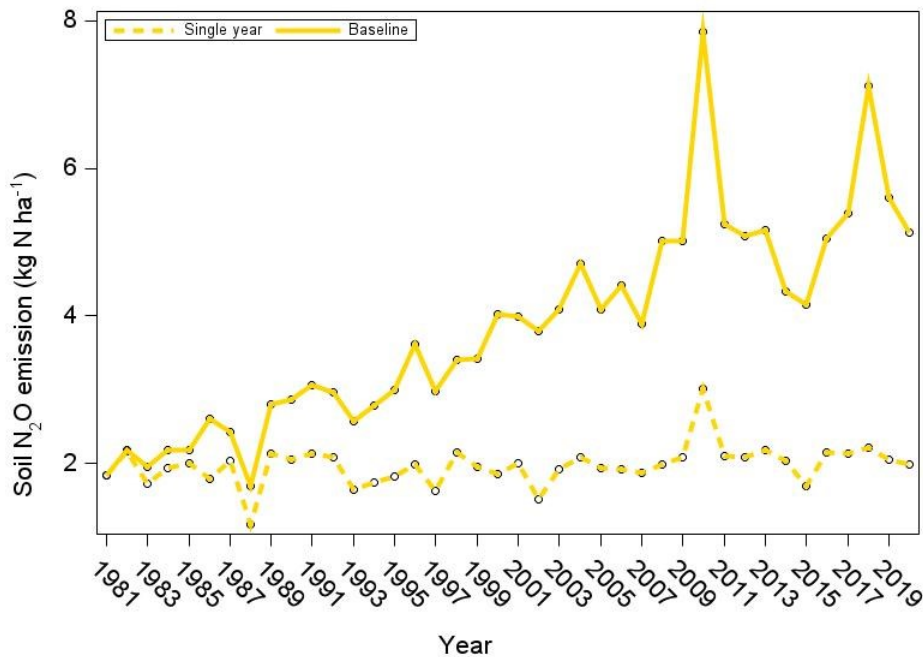
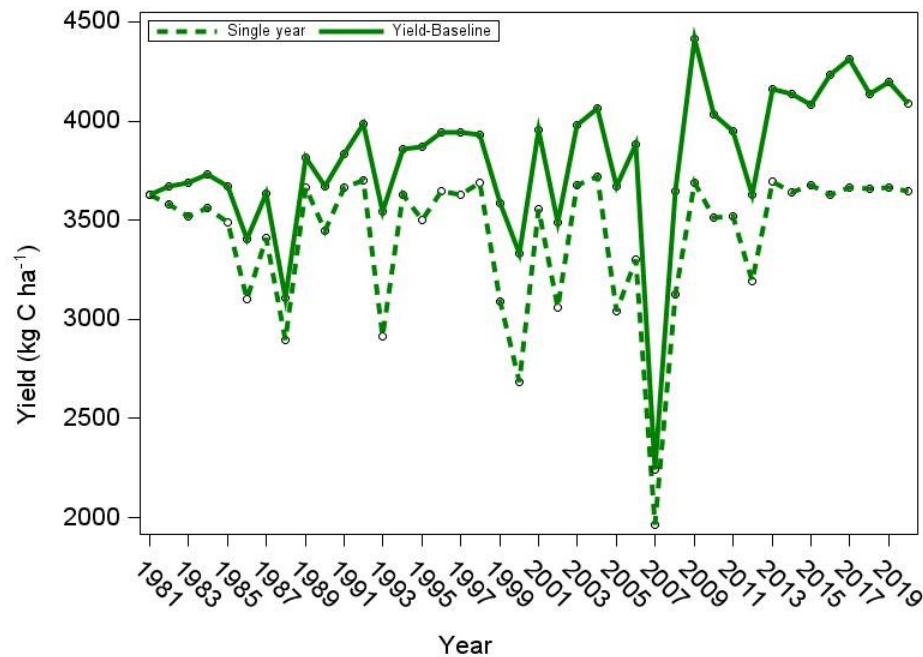
Soil N₂O: 36.58

Legacy effect (Slope):

Yield: 11.24 kg C ha⁻¹ year⁻¹

Soil N₂O: 0.10 kg N ha⁻¹ year⁻¹

Hui et al. 2025. *Fronti. of Earth Science*



Model Simulations

Ambient climate: 40 years' daily data from 1981 to 2020, in Nashville, TN, USA (NASA)

Treatments: 20, a precipitation gradient from severe drought to extreme wet conditions

-90%, -80%, -70%, -60%, -50%, -40%, -30%, -20%, -10%, ambient, +10%, +20%, +30%, +40%, +60%, +70% +80%, +90%, +100%

For each treatment, daily simulation from 1981 to 2020 (40 years), total: 800 years

Outputs: Crop yield and soil N₂O emissions.

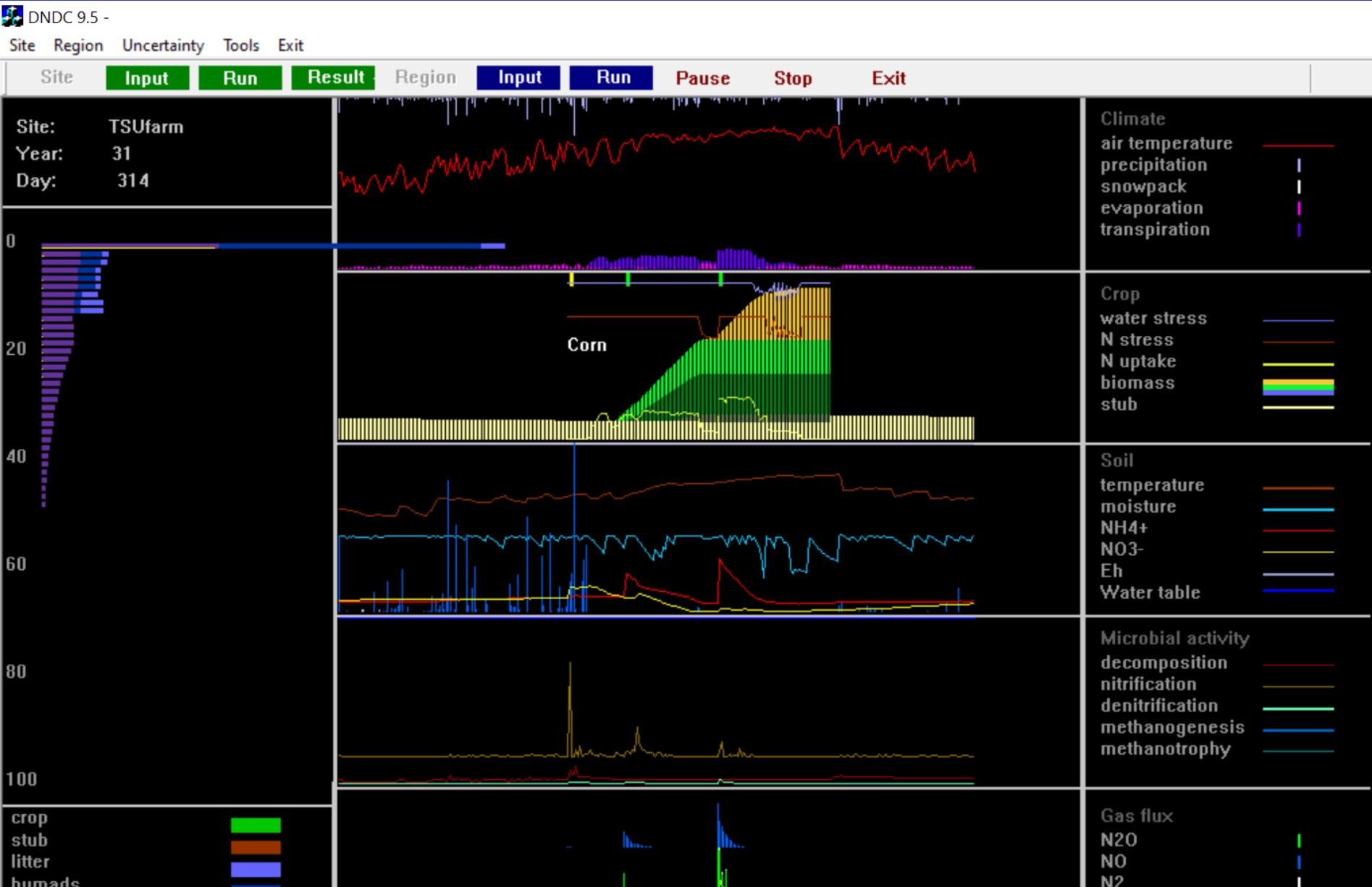
Model Simulations

Model setting and inputs (validated DNDC):
Soil properties: Bulk density, particle size etc.
Crop: Corn, planting date, harvesting date etc.
Management: N application, 218 kg N ha⁻¹ (No irrigation, no-tillage or any other practices)

Climate factors: daily temperature and precipitation (1981-2020)

Daily simulation from 1981 to 2020 (40 years, baseline)

DNDC Model Interface



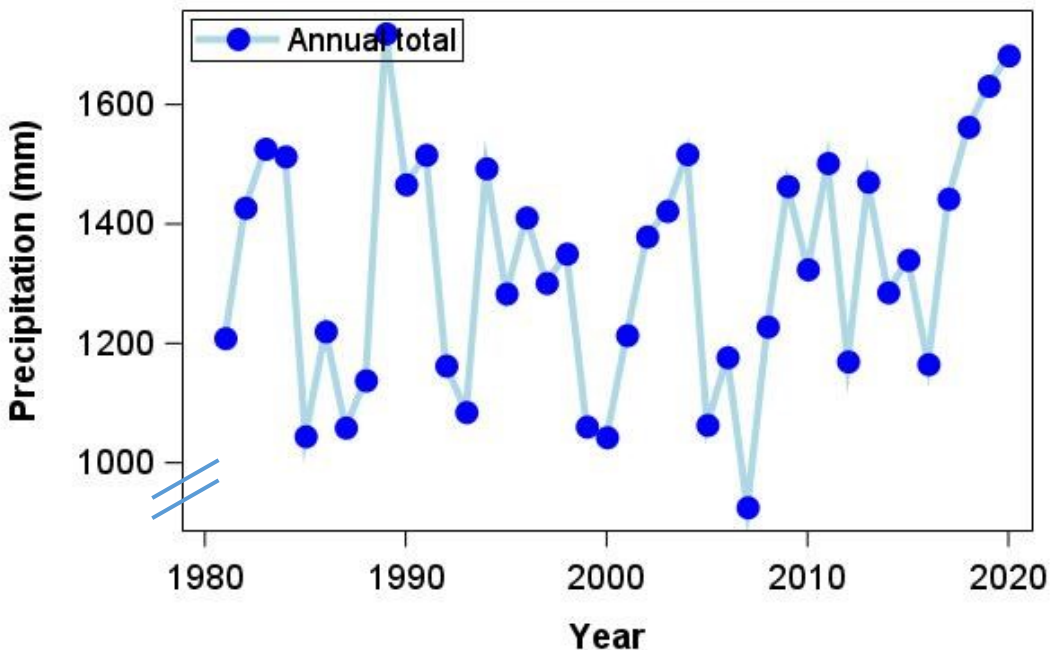
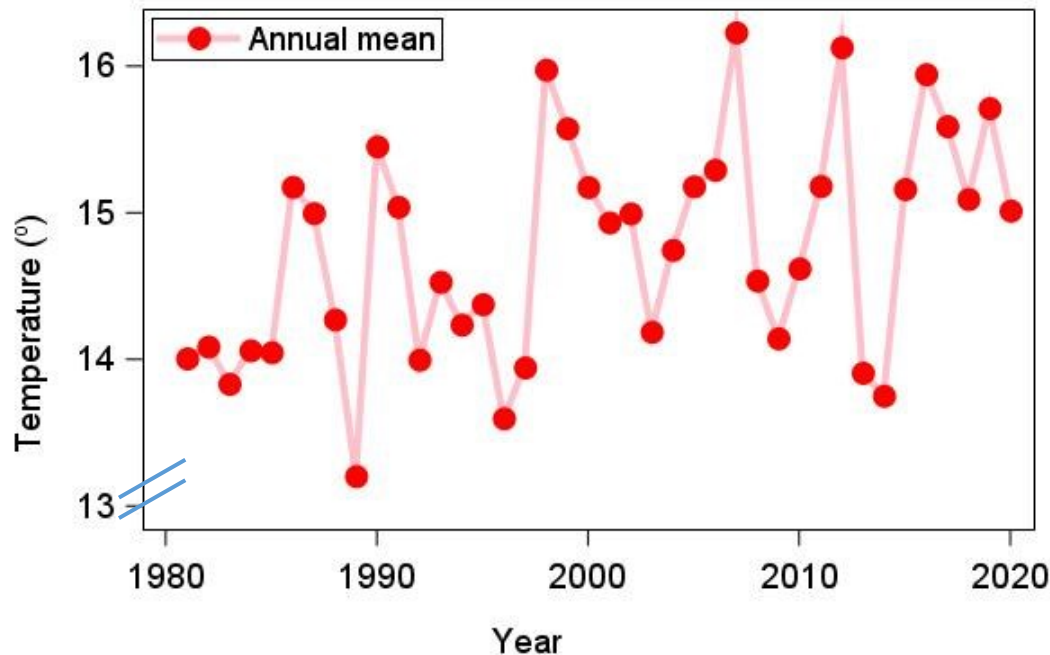
Temperature and Precipitation

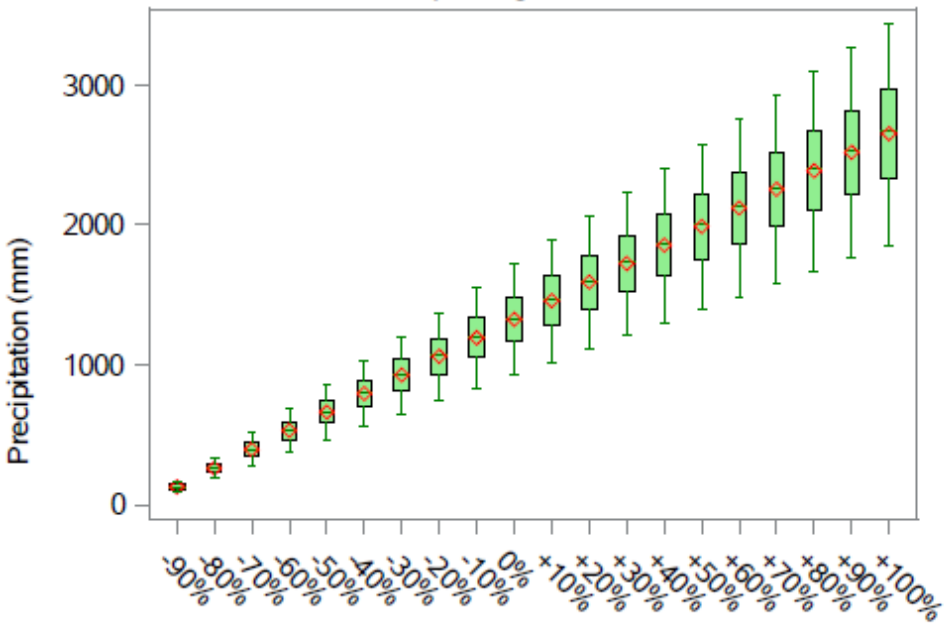
Source: NASA CERES/MERRA2 (1981-2020). Daily temperature and total precipitation

Annual mean/total temperature and precipitation showed large interannual variability.

Interannual variability (CV):
MAT: 5.12
MAP: 14.87

Hui et al. 2025. *Fronti. Of Earth Sci.*





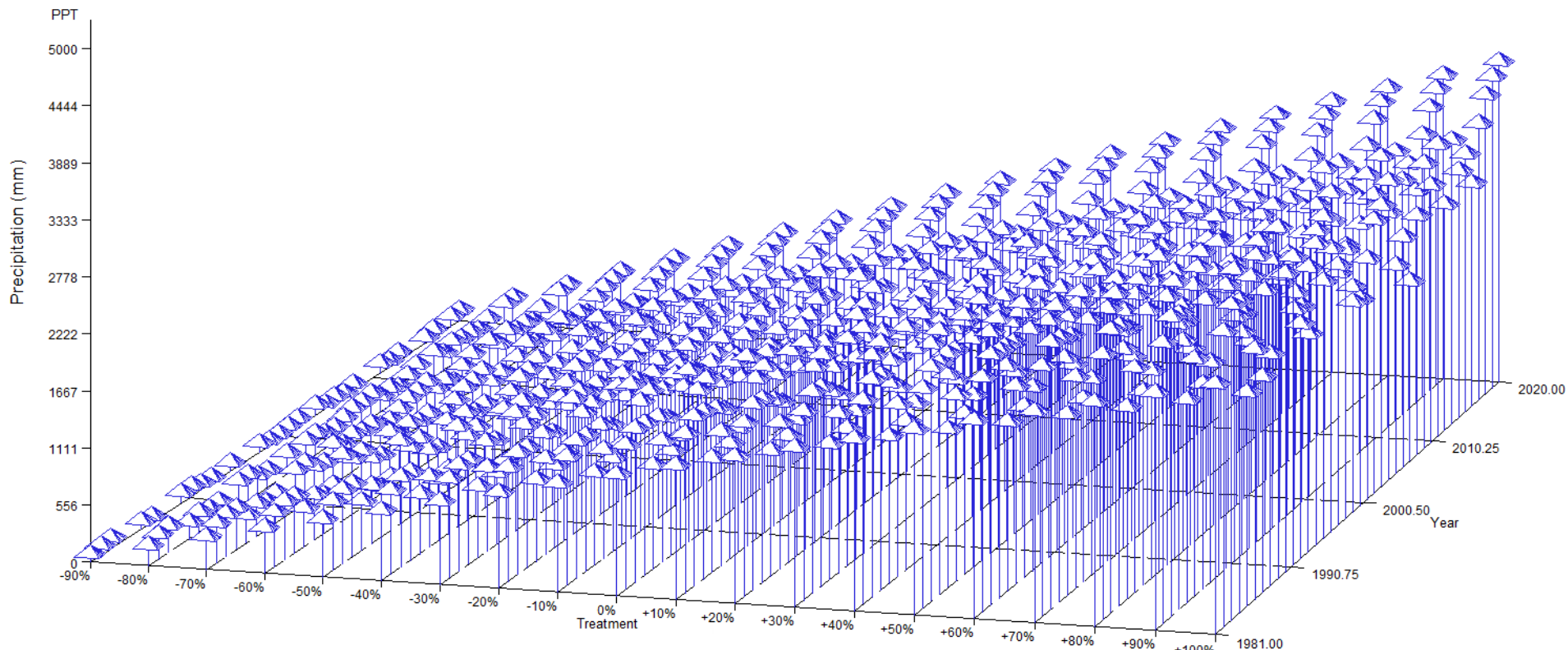
Precipitation Treatments:

-90%: 132 mm

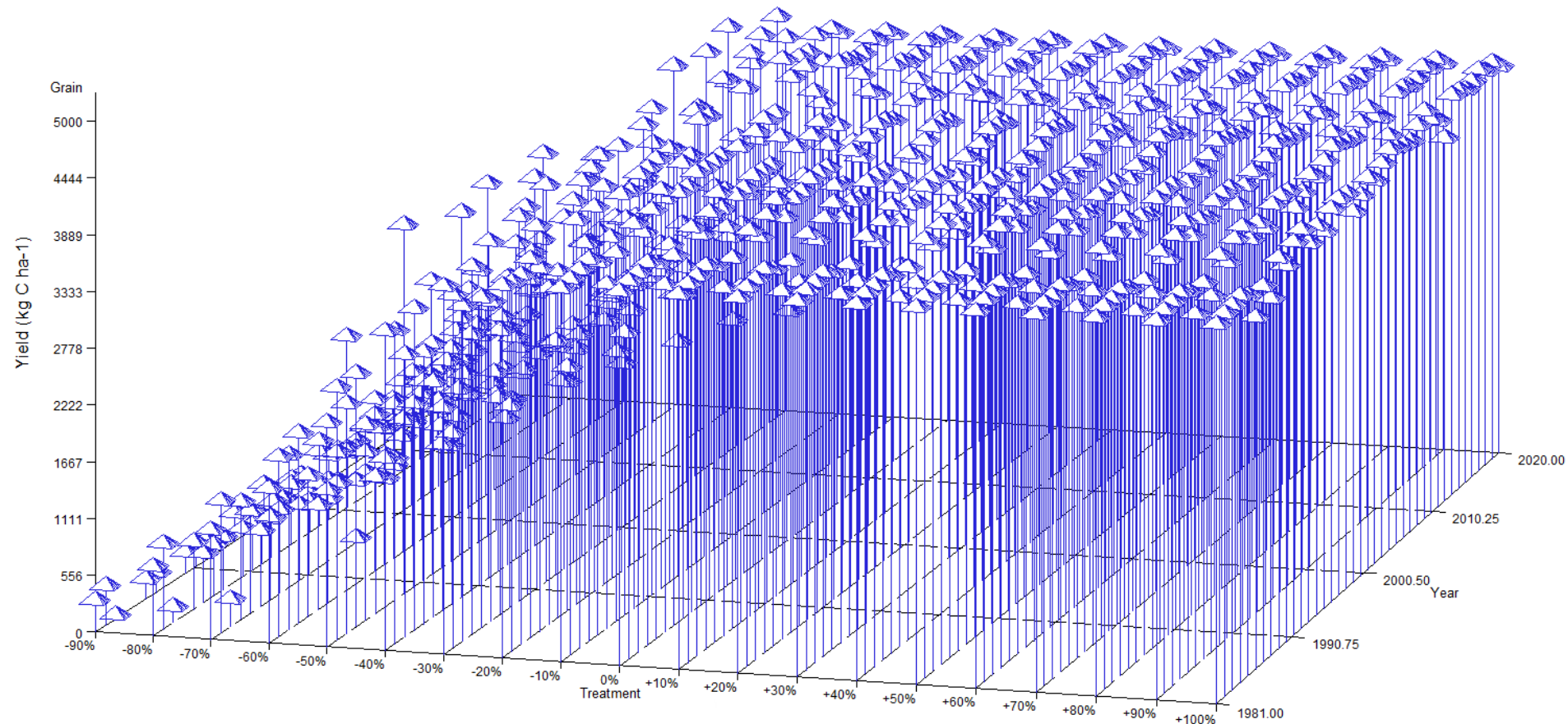
Ambient: 1322 mm

+100%: 2644 mm

CV=14.3



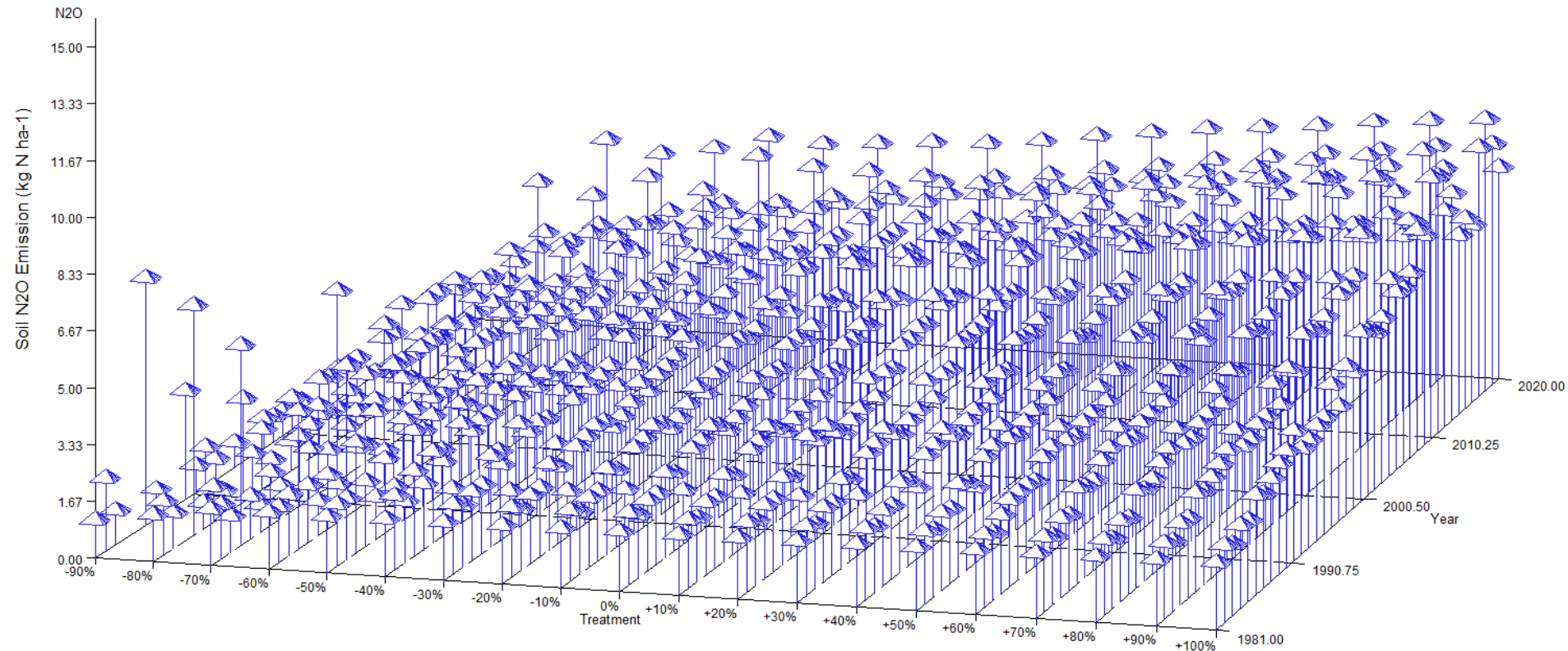
Simulated Corn Yield (kg C ha⁻¹)



Drought treatments significantly reduced corn yield, increasing precipitation did not.

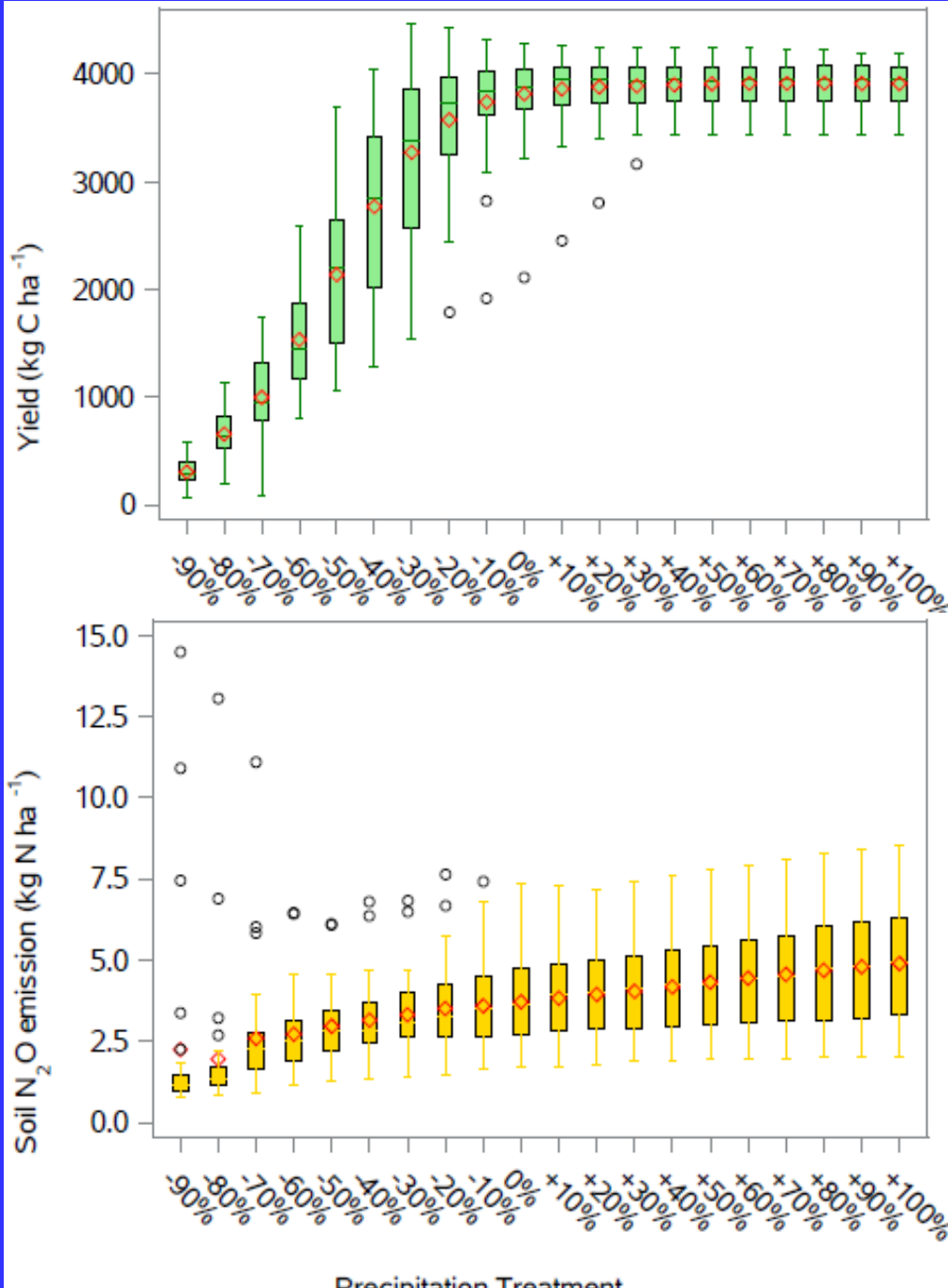
Interannual variability was larger in the drought treatments compared to wet treatments

Simulated Soil N₂O Emissions (kg N ha⁻¹)



Different response patterns were found for soil N₂O emissions compared to yield
Soil N₂O emissions increased with precipitation increases.
Interannual variability was observed for both droughts and wet treatments.

Effect of Precipitation Change on Yield and Soil N₂O Emissions

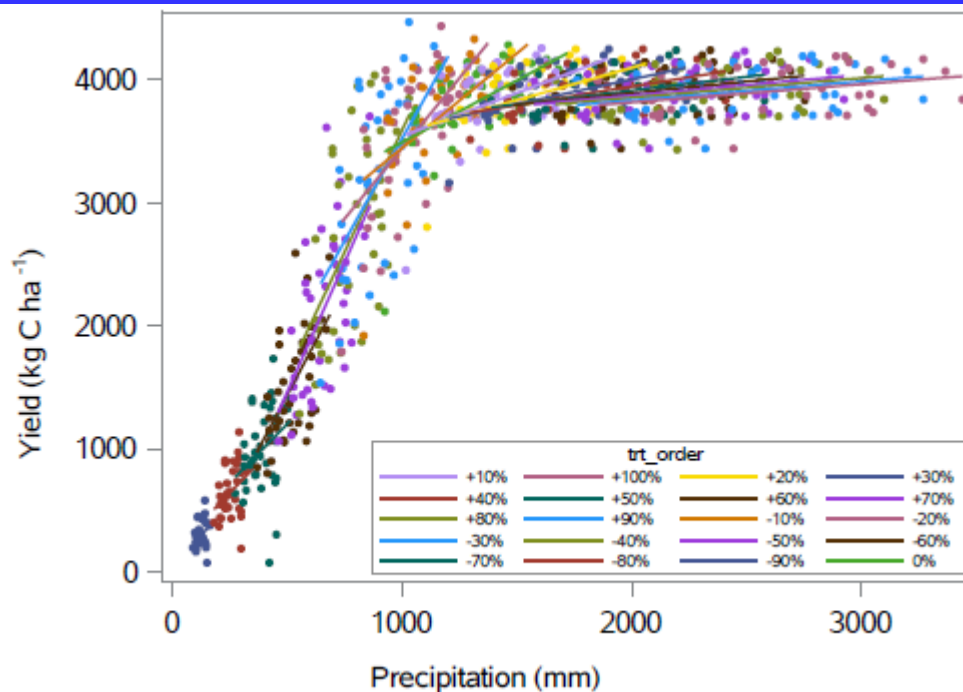


Across the treatments, yield increased with precipitation and then leveled off.

Compared to ambient, drought significantly reduced crop yield, but adding more water did not change much.

Soil N₂O emissions increased with precipitation.

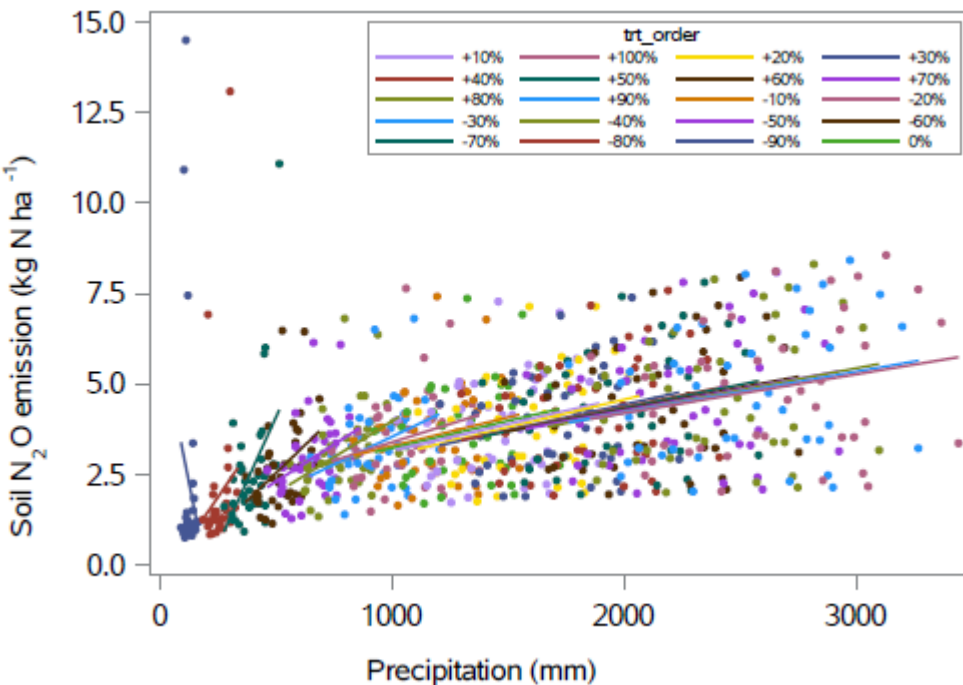
Relationship Between Yield (N_2O) and Precipitation under Different Treatments



40 years data within each treatment

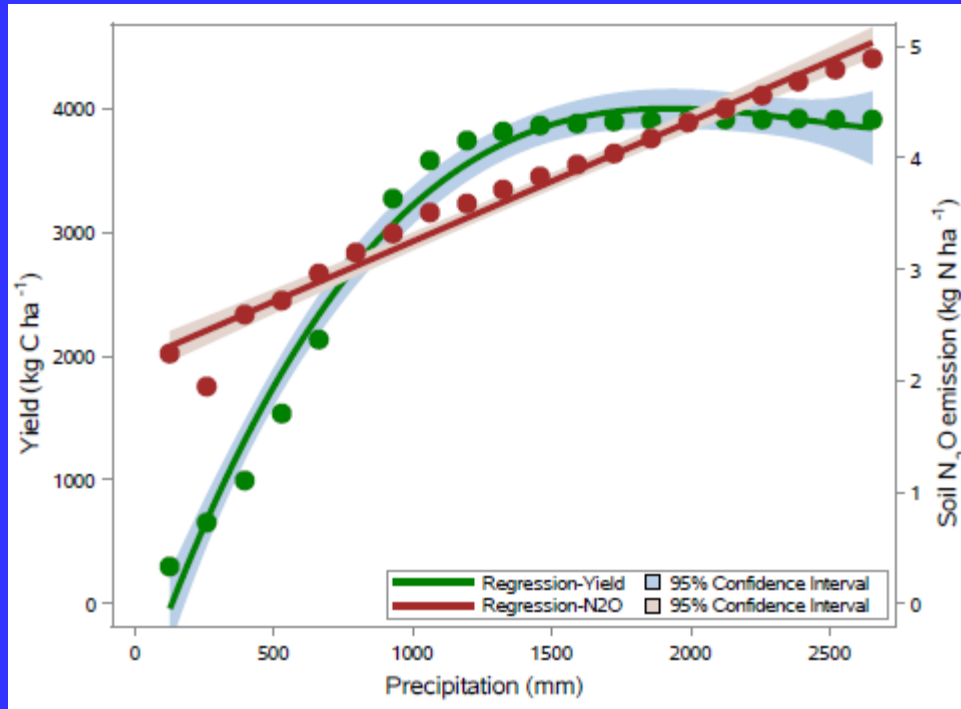
Yield increased linearly with precipitation for most treatments.

Soil N_2O emissions significantly increased with precipitation among the drought treatments (-30%~-70%), not sensitive under wet treatments.



Both are sensitive to drought.

Optimal Precipitation and Threshold Values



Point Type	Precipitation	Yield	N ₂ O
z-score intersection	523.2114	1840.64	2.736
z-score intersection	1947.589	3999.86	4.274
maximum Yield	1922.320	4000.21	.

Yield reached the highest value when mean annual precipitation = 1922 mm;
Soil N₂O emissions per unit yield were low when precipitation was between 523 and 1947 mm. Otherwise, precipitation favored soil N₂O emissions more than yield.

Summary

- Based on a long-term climate dataset, we showed strong drought impacts on corn yield and soil N₂O emissions using the DNDC model
- Nonlinear and asymmetric responses were found as corn yield is very sensitive to drought, but less to precipitation increase
- Soil N₂O emissions increase continuously from drought to very wet conditions
- Adaptive and optimal management of precipitation/irrigation may offer an effective strategy for crop productivity and mitigating greenhouse gas emissions

Acknowledgements

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