Significance of Irrigation for Crop Production: From the Global and China Perspectives

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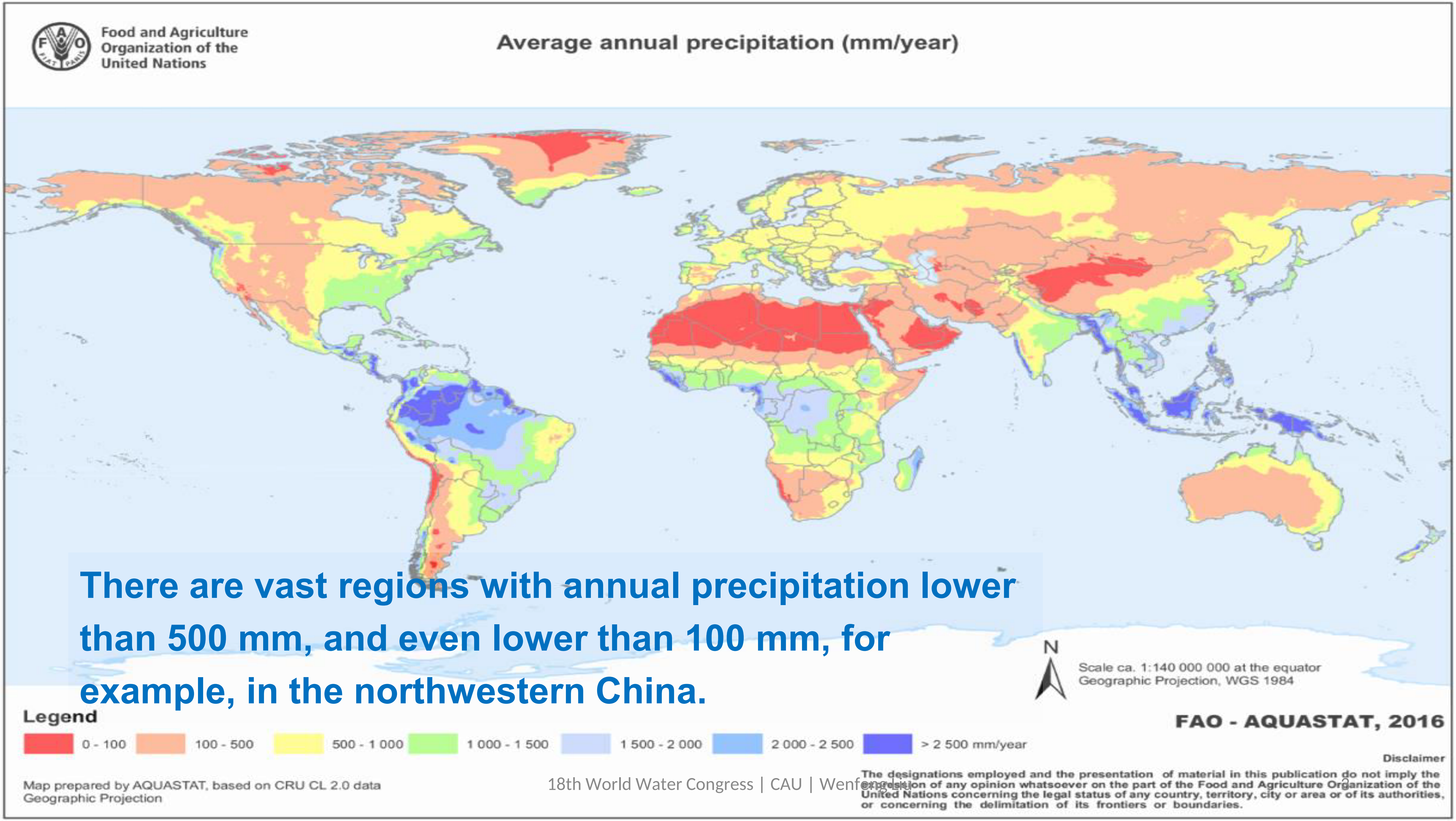
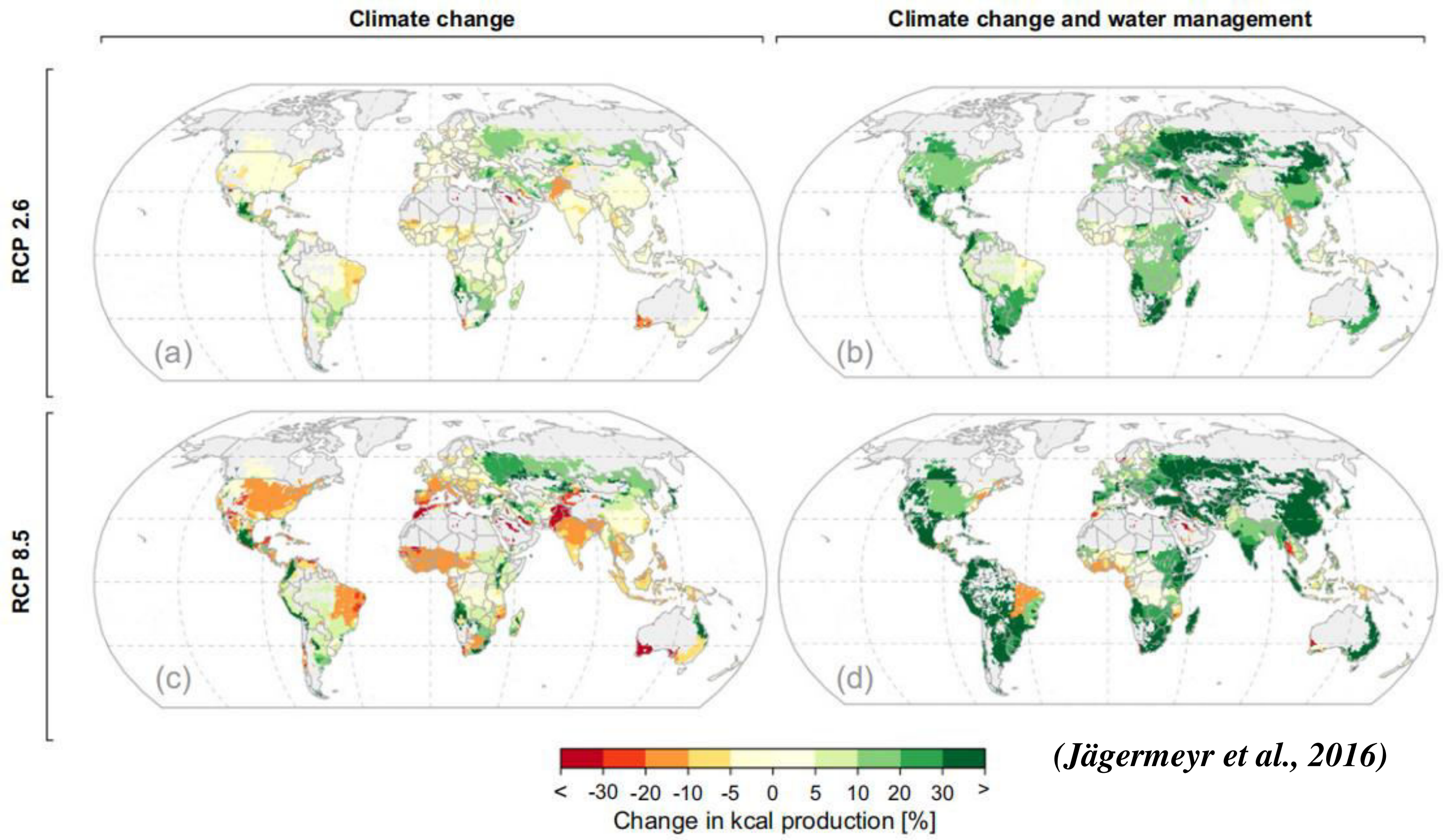
2023-09-13

Outlines

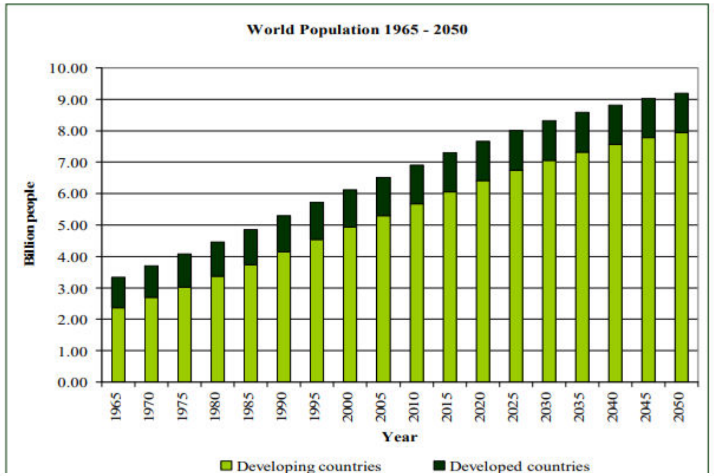


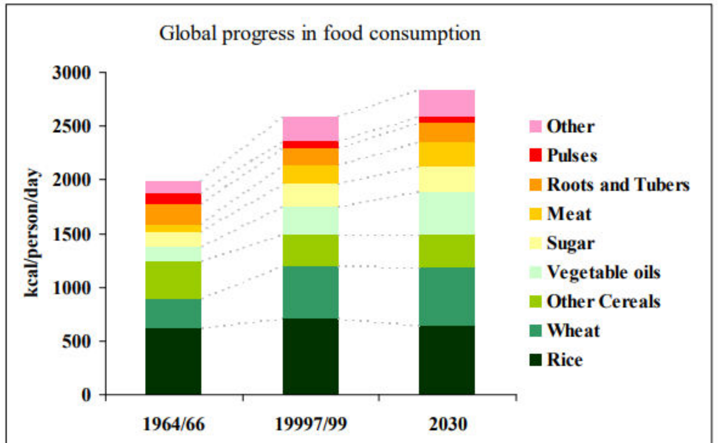
There are vast regions with annual precipitation lower than 500 mm, and even lower than 100 mm, for example, in the northwestern China.

Introduction



(Jägermeyr et al., 2016)

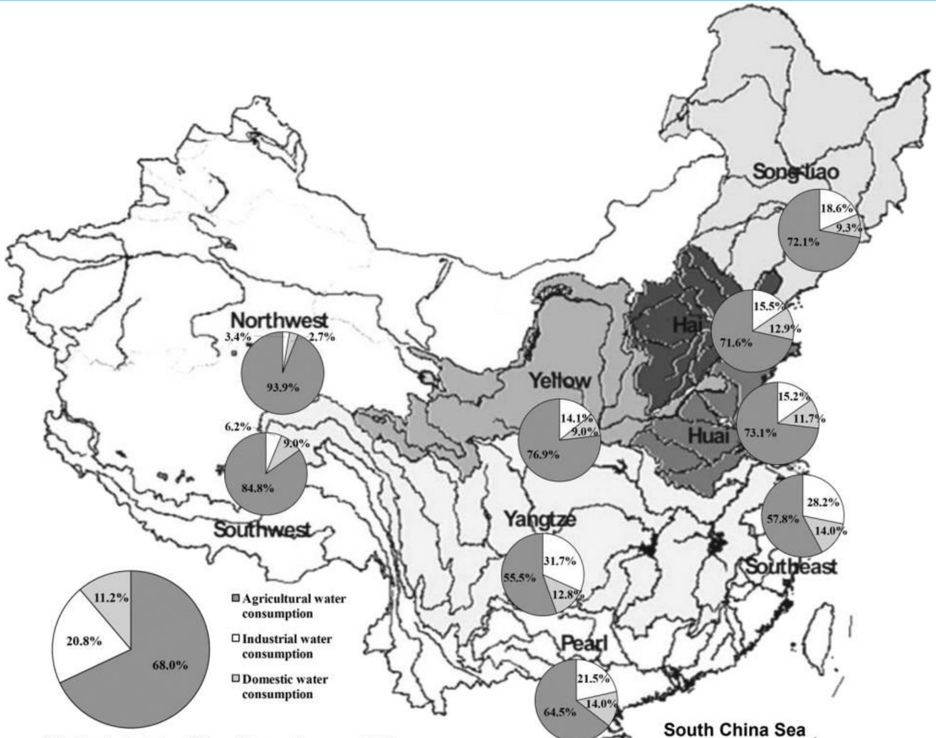




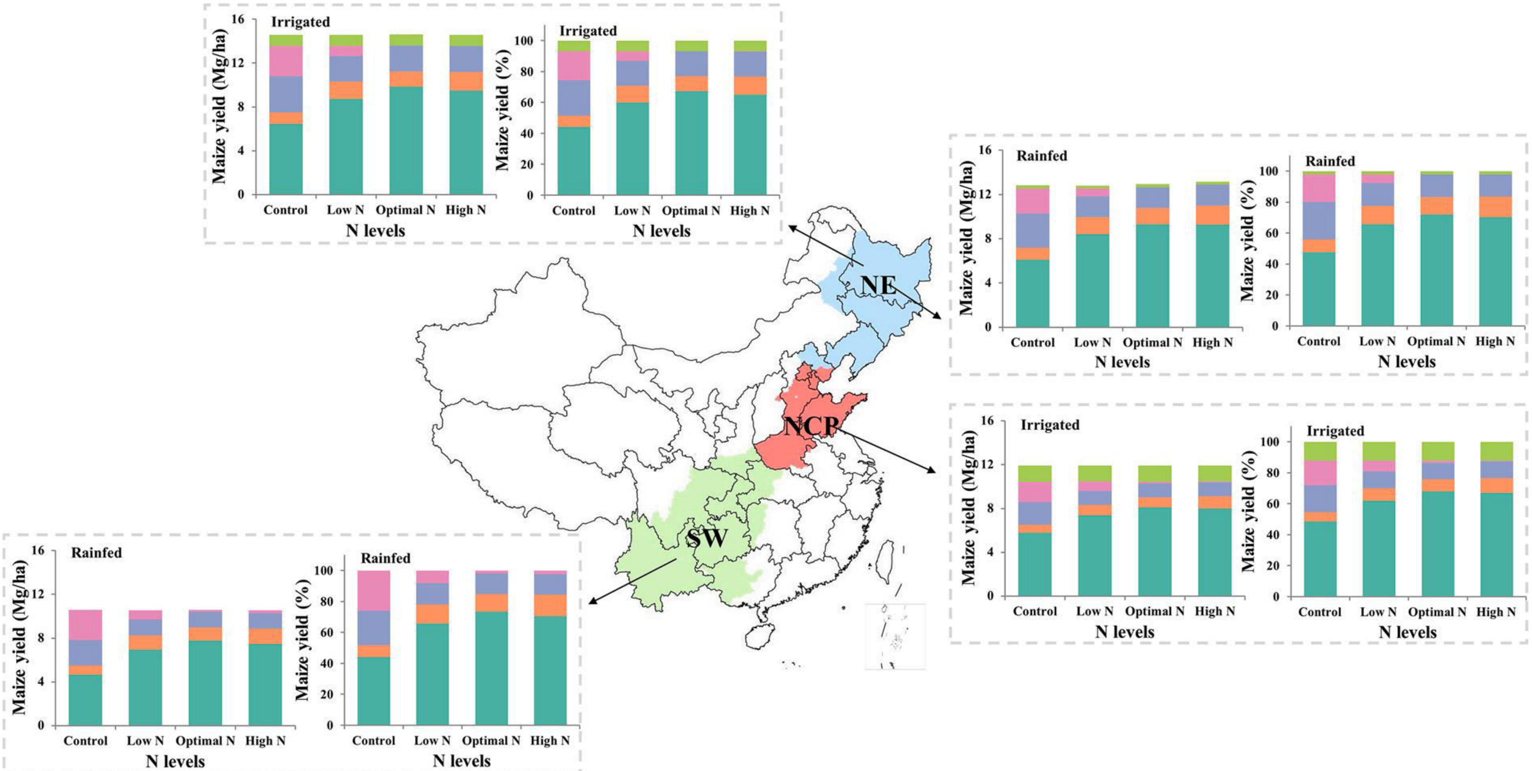
(FAOSTAT, 2020)

- Improving irrigation is a possible option to **achieve higher yield level**s in water-limited regions while **improving the resilience of cropping systems to climate variability** and making it possible to feed the world's growing population and meet the food demand (*Wang et al., 2021; Okada et al., 2018; Jägermeyr et al., 2016*).

Introduction



(Du et al., 2014)

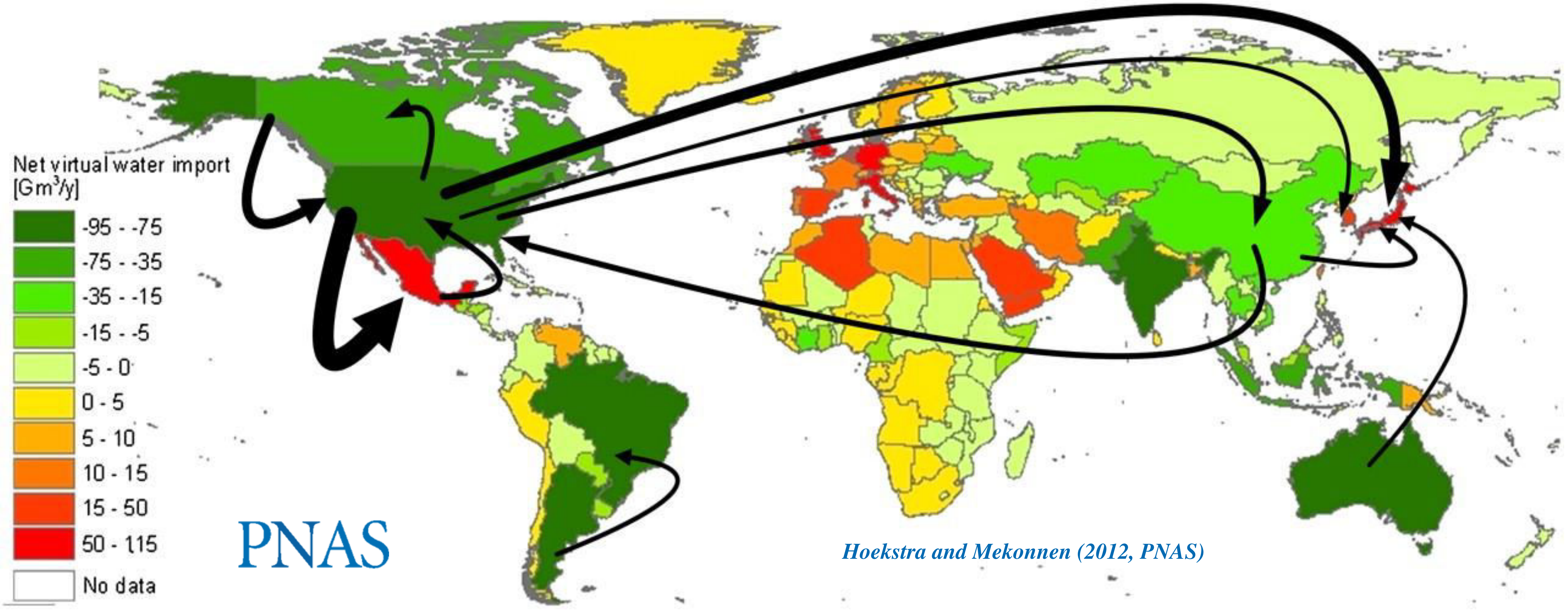


(Qiao et al., 2021)

- Under optimal N management, irrigated maize yield is **16–26% higher than** that under rainfed (*Qiao et al., 2021*).
- China ranks first with 95.5 million ha of irrigated area in the world (*FAOSTAT, 2020*). Agricultural water use accounts for 68% of the total water supply, especially in **northwestern China is about 90%** (*Du et al., 2014; Kang et al., 2017*).

Introduction

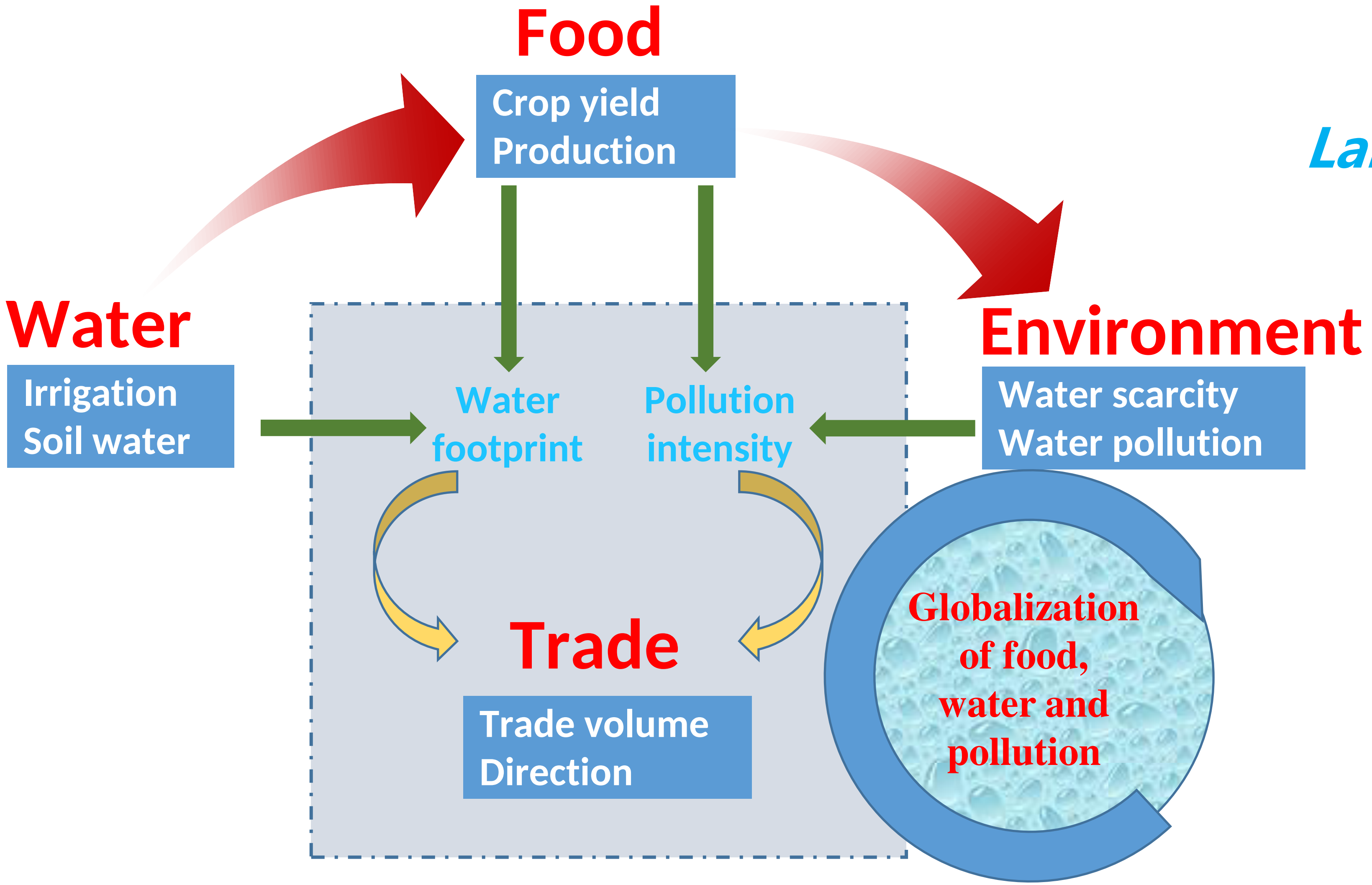
Global virtual water trade embodied in crop trade.



Virtual water balance per country and direction of gross virtual water flows related to trade in agricultural and industrial products over the period 1996–2005.

Introduction

➢ **Strong Water-Food-Environment-Trade nexus, and Water-Food-Energy nexus.**



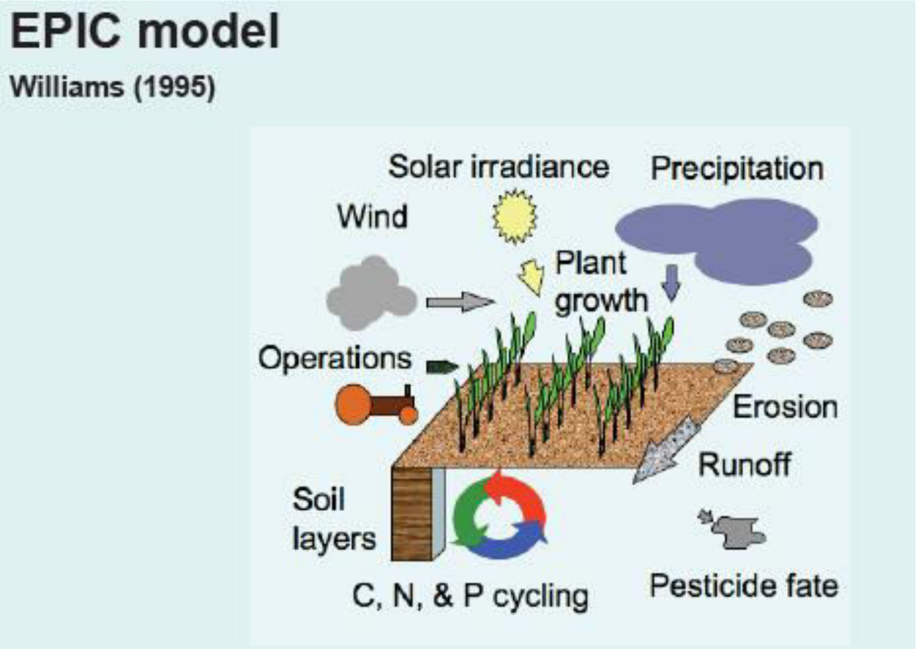
Large-scale questions:

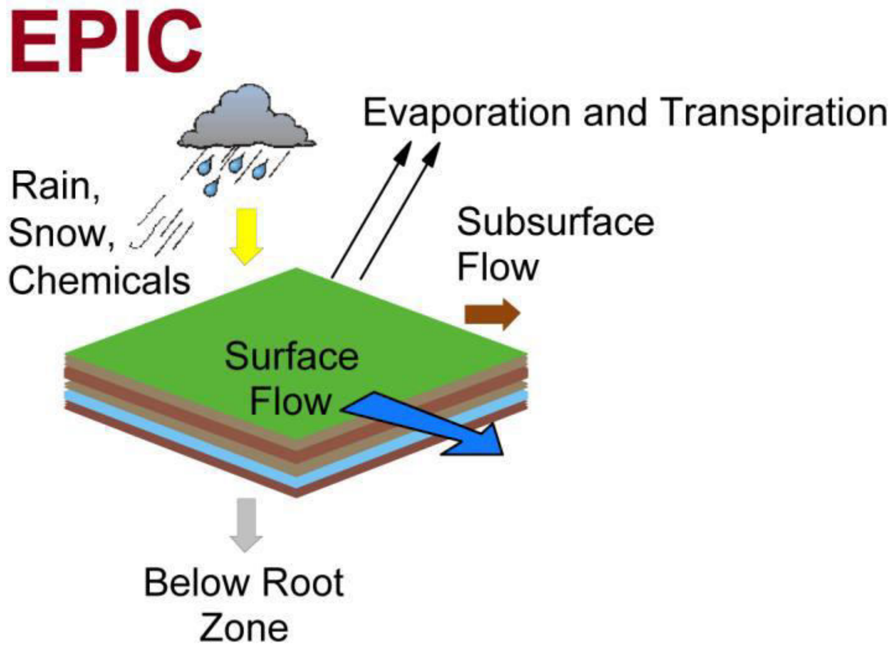
*The contribution of irrigation to yield benefits **on a large scale?***

*How to **reduce irrigation water consumption** and mitigate the related challenges globally?*

Simulation framework

➢ **EPIC: Environmental Policy Integrated Climate**



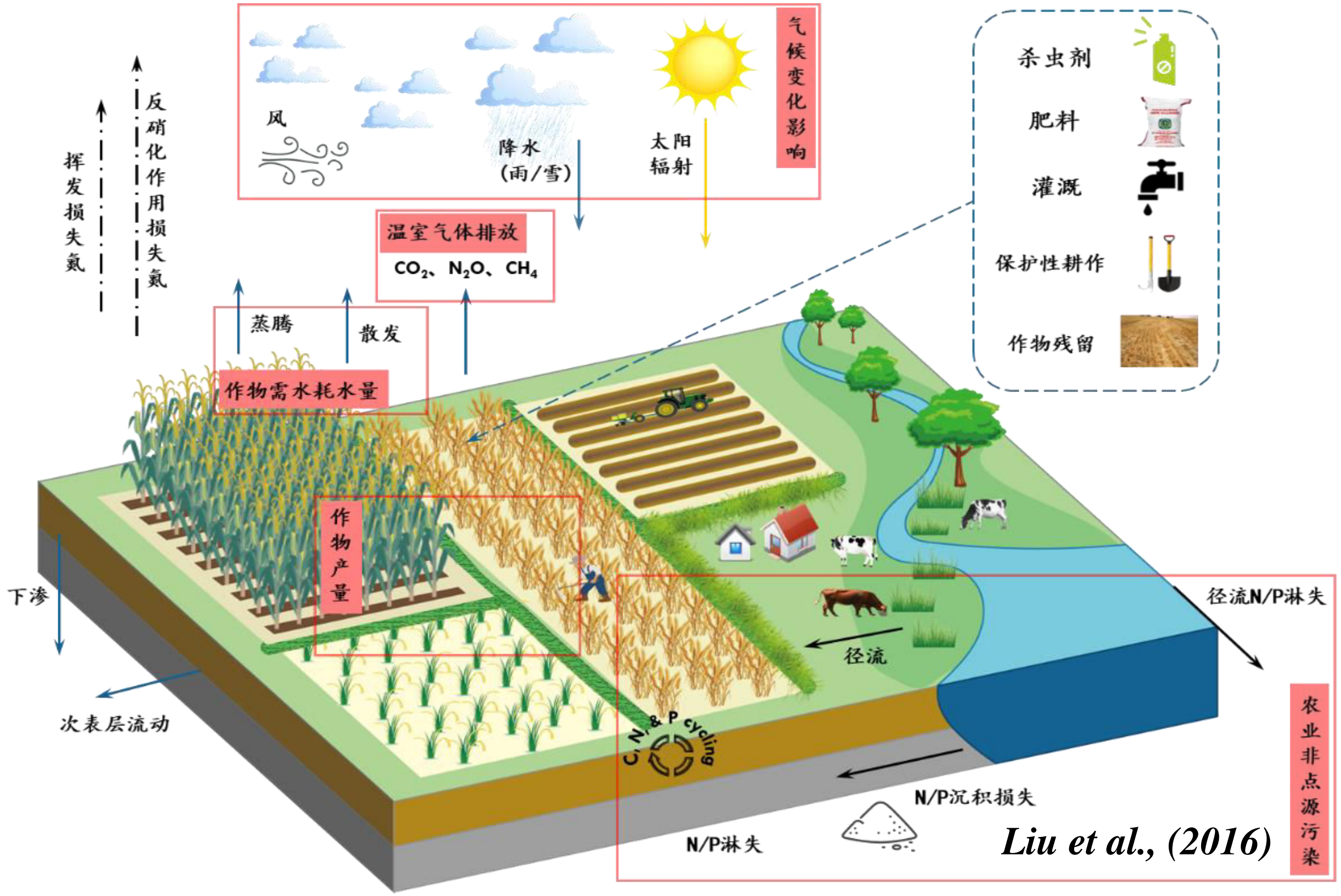


- Wide application and good performance: USA, China, Canada, France, Argentina, Brazil, India, etc.
- Free availability: Downloadable with source code from http://epicapex.tamu.edu/epic/.
- Technical feasibility: Platform independent command-line program.
- Low data requirement: Soil, climate, crop distribution, management practices.
- One model for different crops: > 100 crops.

A simple model, but with complex soil-water-climate-environment interplays.

Simulation framework

EPIC → PEPIC (for large scale simulations)



Liu et al., (2016)

What we can do:

- ✓ Irrigation contribution;
- ✓ Cropland redistribution;
- ✓ Multiple-models uncertainty;
- ✓ Combining with large-scale hydrological models;
- ✓ Combining with economic analysis methods;
- ✓ Scenario analyses;
- ✓ Climate change impacts;

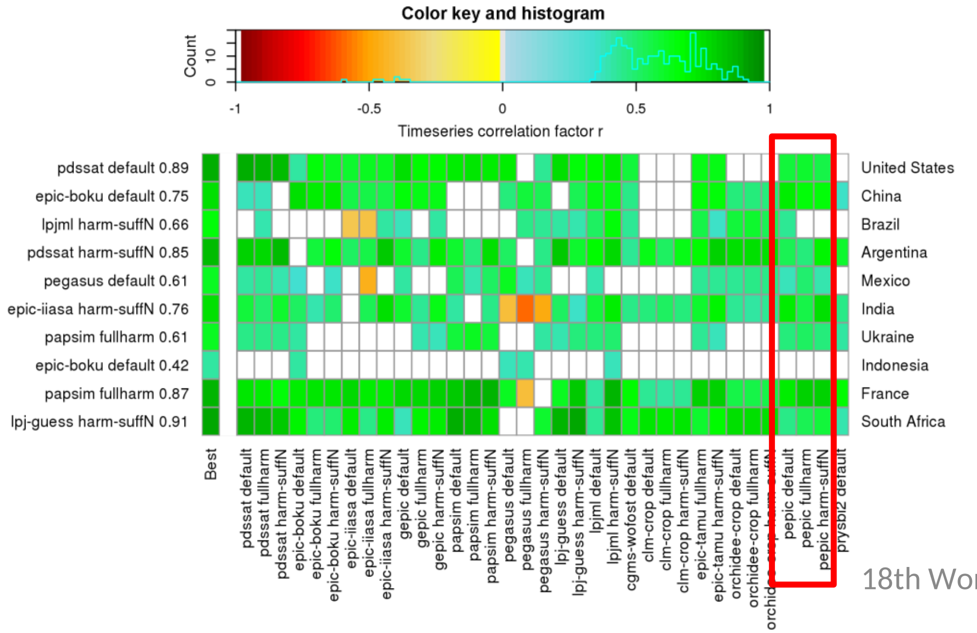
…

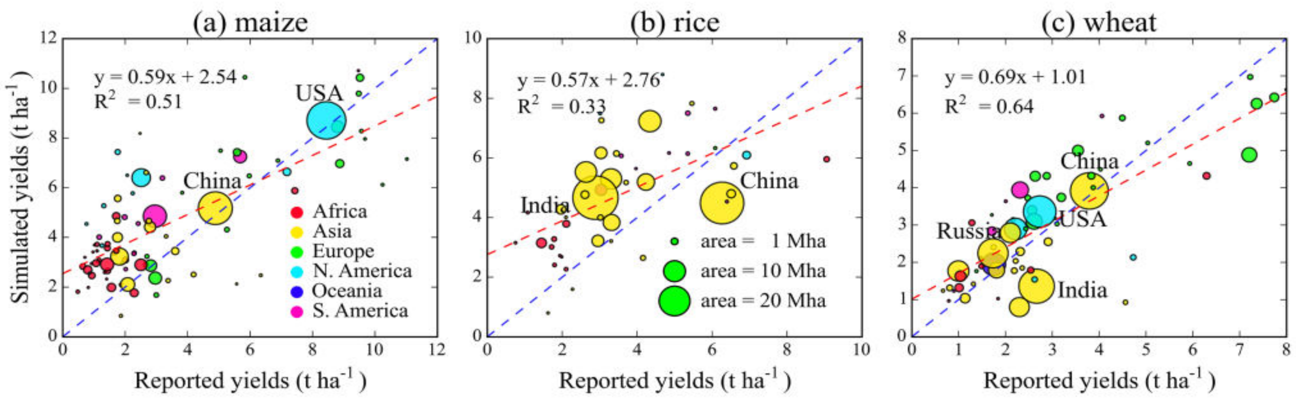
Simulation framework

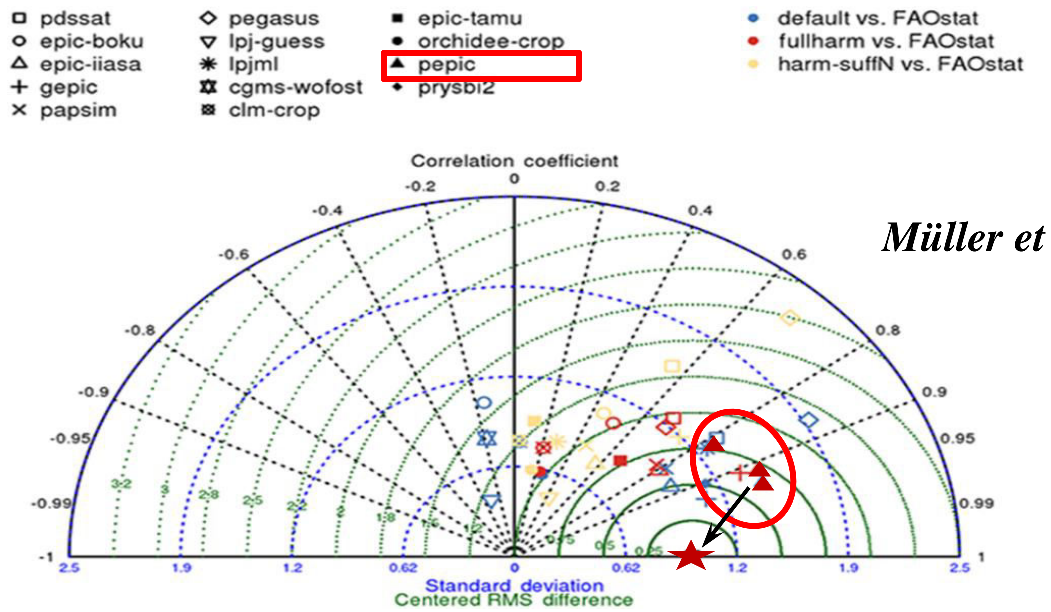
- The PEPIC model has been one of the key models in ISIMIP and AgMIP.

AgMIP The Agricultural Model Intercomparison and Improvement Project

Crop model	Model type
CGMS-WOFOST	Site-based process model
CLM-Crop	Ecosystem Model
EPIC-BOKU	Site-based process model (based on EPIC)
EPIC-IIASA	Site-based process model (based on EPIC)
EPIC-TAMU	Site-based process model (based on EPIC)
GEPIC	Site-based process model (based on EPIC)
LPJ-GUESS	Ecosystem Model
LPJmL	Ecosystem Model
ORCHIDEE-crop	Ecosystem Model
pAPSIM	Site-based process model
pDSSAT	Site-based process model
PEGASUS	Ecosystem model
PEPIC	Site-based process model (based on EPIC)
PRYSBI2	Empirical/process hybrid







Müller et al. (2017, GMD)

Simulation framework

A regional nuclear conflict would compromise global food security

PNAS

a,b,c,1, Alan Robock[d], Joshua Elliott[a], Christoph Müller[c], Lili Xia[d], Nikolay Khaba
h[e], Erwin Schmid[f], Wenfeng Liu[g,h], Florian Zabel[i], Sam S. Rabin[j], Michael J. Puma[b,k], Alison Heslin[b,k],
n Foster[a,m], Senthold Asseng[n], Charles G. Bardeen[o,p], Owen B. Toon[p], and Cynthia Rosenzweig[b,k]

POLICY FORUM | CLIMATE CHANGE

Intergenerational inequities in exposure to climate extremes

Young generations are severely threatened by climate change

Science JOURNALS AAAS

WIM THIERY, STEFAN LANGE, JOERI ROGELJ, CARL-FRIEDRICH SCHLEUSSNER, LUKAS GUDMUNDSSON, SONIA I. SENEVIRATNE, MARINA ANDRIJEVIC, KATJA FRIELER, KERRY EMANUEL, [...], AND YOSHIHIDE WADA +27 authors Authors Info & Affiliations

ARTICLE
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nature COMMUNICATIONS
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Potential impacts of climate change on agriculture and fisheries production in 72 tropical coastal communities

Joshua E. Cinner[1✉], Iain R. Caldwell[1], Lauric Thiault[2,3], John Ben[4], Julia L. Blanchard[5,6], Marta Coll[7], Amy Diedrich[8,9], Tyler D. Eddy[10], Jason D. Everett[11,12,13], Christian Folberth[14], Didier Gascuel[15], Jerome Guiet[16], Georgina G. Gurney[1], Ryan F. Heneghan[17], Jonas Jägermeyr[18,19,20], Narriman Jiddawi[21], Rachael Lahari[22], John Kuange[23], Wenfeng Liu[24], Olivier Maury[25], Christoph Müller[20], Camilla Novaglio[5,6], Juliano Palacios-Abrantes[26,27], Colleen M. Petrik[28], Ando Rabearisoa[29], Derek P. Tittensor[30,31], Andrew Wamukota[32] & Richard Pollnac[33,34]

Climate impacts on global agriculture emerge earlier in new generation of climate and crop models

nature food

Jonas Jägermeyr[1,2,3✉], Christoph Müller[3], Alex C. Ruane[1], Joshua Elliott[4], Juraj Balkovic[5,6], Oscar Castillo[7], Babacar Faye[8], Ian Foster[9], Christian Folberth[5], James A. Franke[4,10], Kathrin Fuchs[11], Jose R. Guarin[1,2], Jens Heinke[3], Gerrit Hoogenboom[7,12], Toshichika Iizumi[13], Atul K. Jain[14], David Kelly[9], Nikolay Khabarov[5], Stefan Lange[3], Tzu-Shun Lin[14], Wenfeng Liu[15], Oleksandr Mialyk[16], Sara Minoli[3], Elisabeth J. Moyer[4,10], Masashi Okada[17], Meridel Phillips[1,2], Cheryl Porter[7], Sam S. Rabin[11,18], Clemens Scheer[11], Julia M. Schneider[19], Joep F. Schyns[16], Rastislav Skalsky[5,20], Andrew Smerald[11], Tommaso Stella[21], Haynes Stephens[4,10], Heidi Webber[21], Florian Zabel[19] and Cynthia Rosenzweig[1]

Large potential for crop production adaptation depends on available future varieties

Global Change Biology

Florian Zabel[1] | Christoph Müller[2] | Joshua Elliott[3] | Sara Minoli[2] | Jonas Jägermeyr[2,3,4] | Julia M. Schneider[1] | James A. Franke[5,6] | Elisabeth Moyer[5,6] | Marie Dury[7] | Louis Francois[7] | Christian Folberth[8] | Wenfeng Liu[9] | Thomas A.M. Pugh[10,11] | Stefan Olin[12] | Sam S. Rabin[13] | Wolfram Mauser[1] | Tobias Hank[1] | Alex C. Ruane[4] | Senthold Asseng[14]

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https://doi.org/10.1038/s41467-021-21498-5 OPEN
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Global irrigation contribution to wheat and maize yield

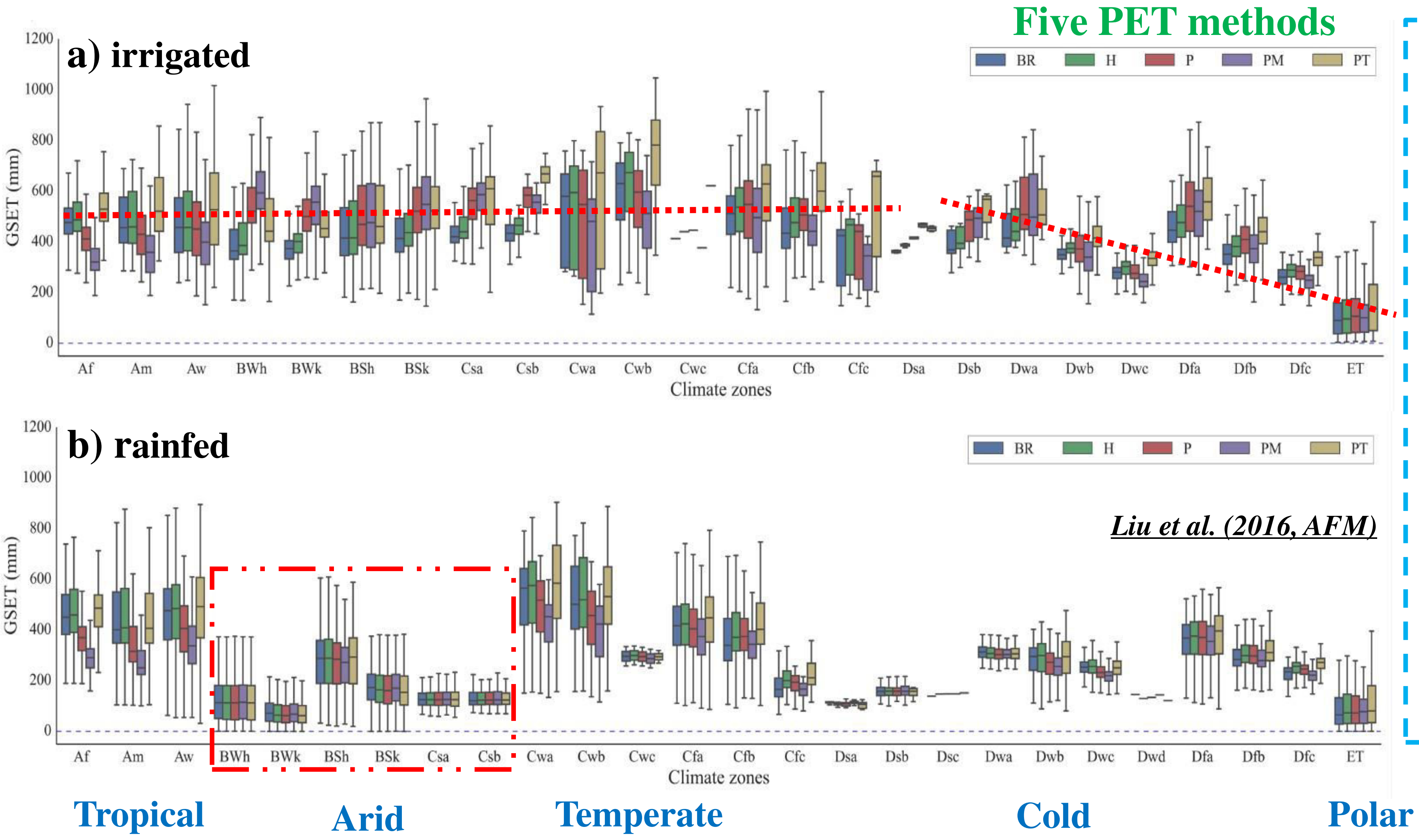
Xuhui Wang[1✉], Christoph Müller[2], Joshua Elliot[3,4], Nathaniel D. Mueller[5,6], Philippe C
Jonas Jägermeyr[3,4], James Gerber[8], Patrice Dumas[9], Chenzhi Wang[1], Hui Yang[1,7], L
Delphine Deryng[11], Christian Folberth[12], Wenfeng Liu[13], David Makowski[14], Stefan C
Thomas A. M. Pugh[15], Ashwan Reddy[16], Erwin Schmid[17], Sujong Jeong[18], Feng Zhou
Shilong Piao[1,19,20]

Global Phosphorus Losses from Croplands under Future Precipitation Scenarios

Environmental Science & Technology

Wenfeng Liu,* Philippe Ciais, Xingcai Liu, Hong Yang, Arjen Y. Hoekstra, Qiuhong Tang, Xuhui Wang, Xiaodong Li, and Lei Cheng

Effects of irrigation——Crop water use

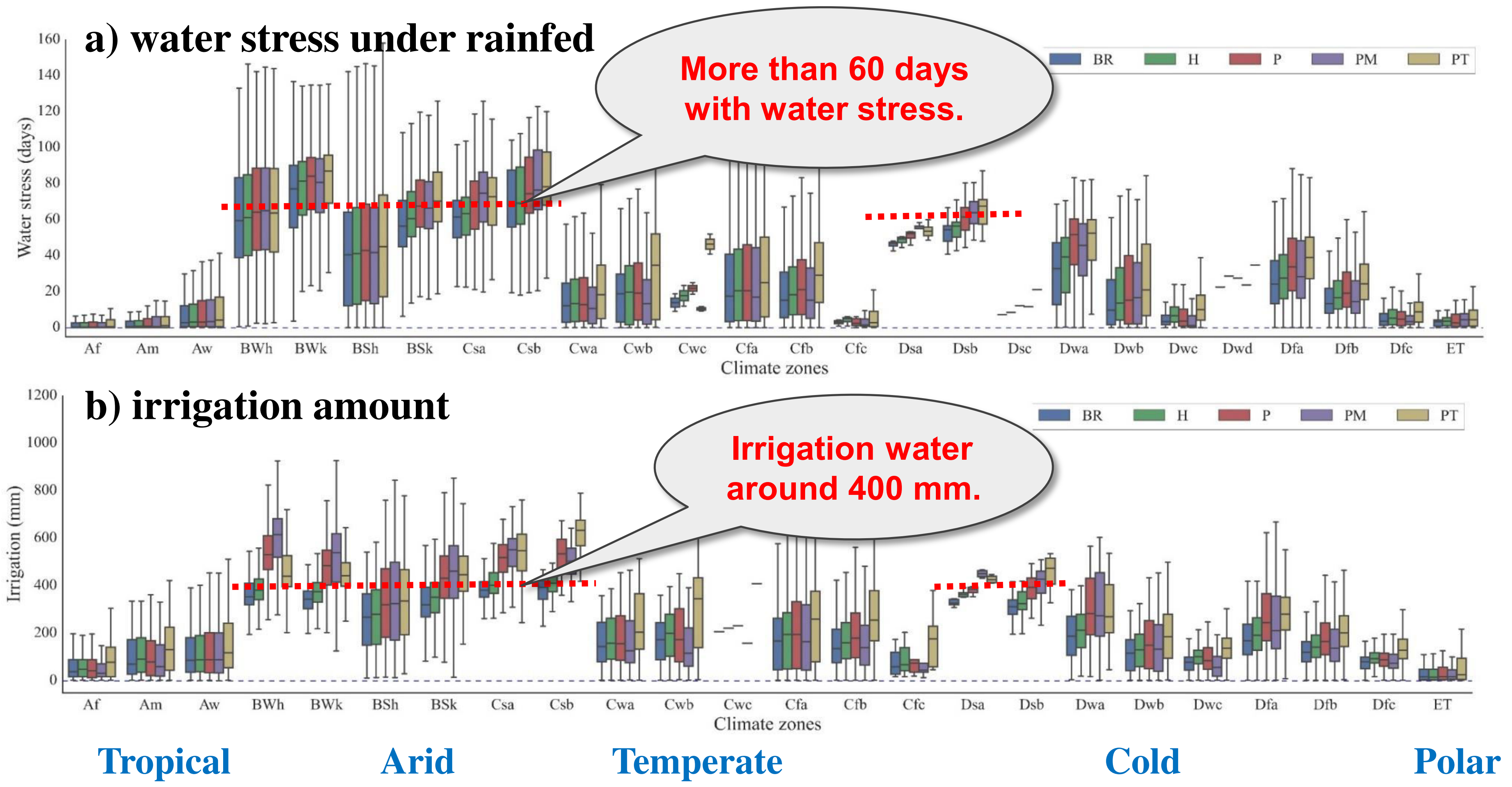


Growing season ET is around 500 mm for tropical, arid, and temperate regions under irrigated cultivation.

However, it declined to lower than 200 mm under rainfed cultivation in arid and part of temperate regions.

Growing season ET of maize at the Köppen-Geiger level for (a) irrigated and (b) rainfed cultivation

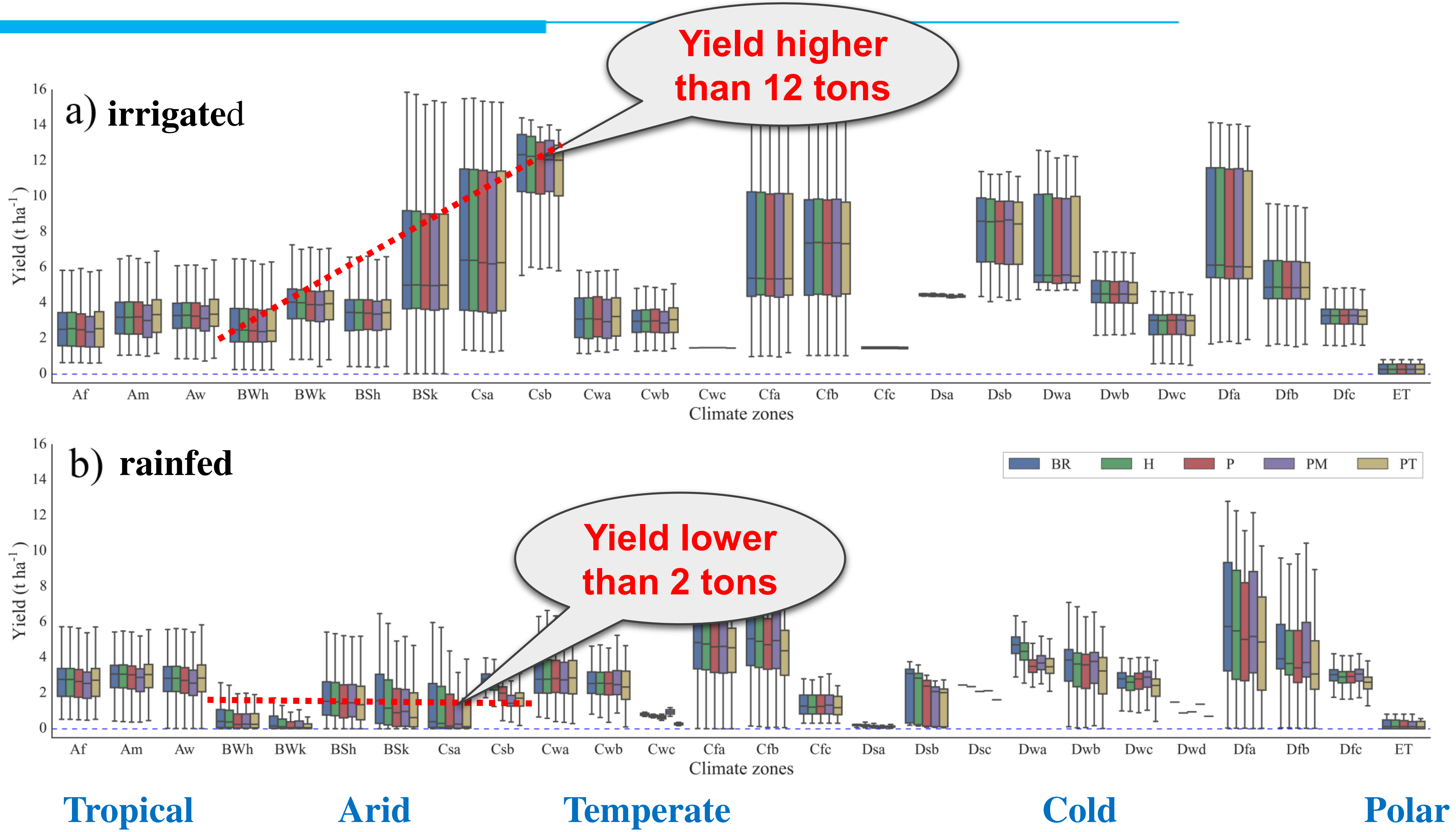
Effects of irrigation——Water stress



Water stress (days, a) and irrigation volume (b) of maize

Liu et al. (2016, AFM)

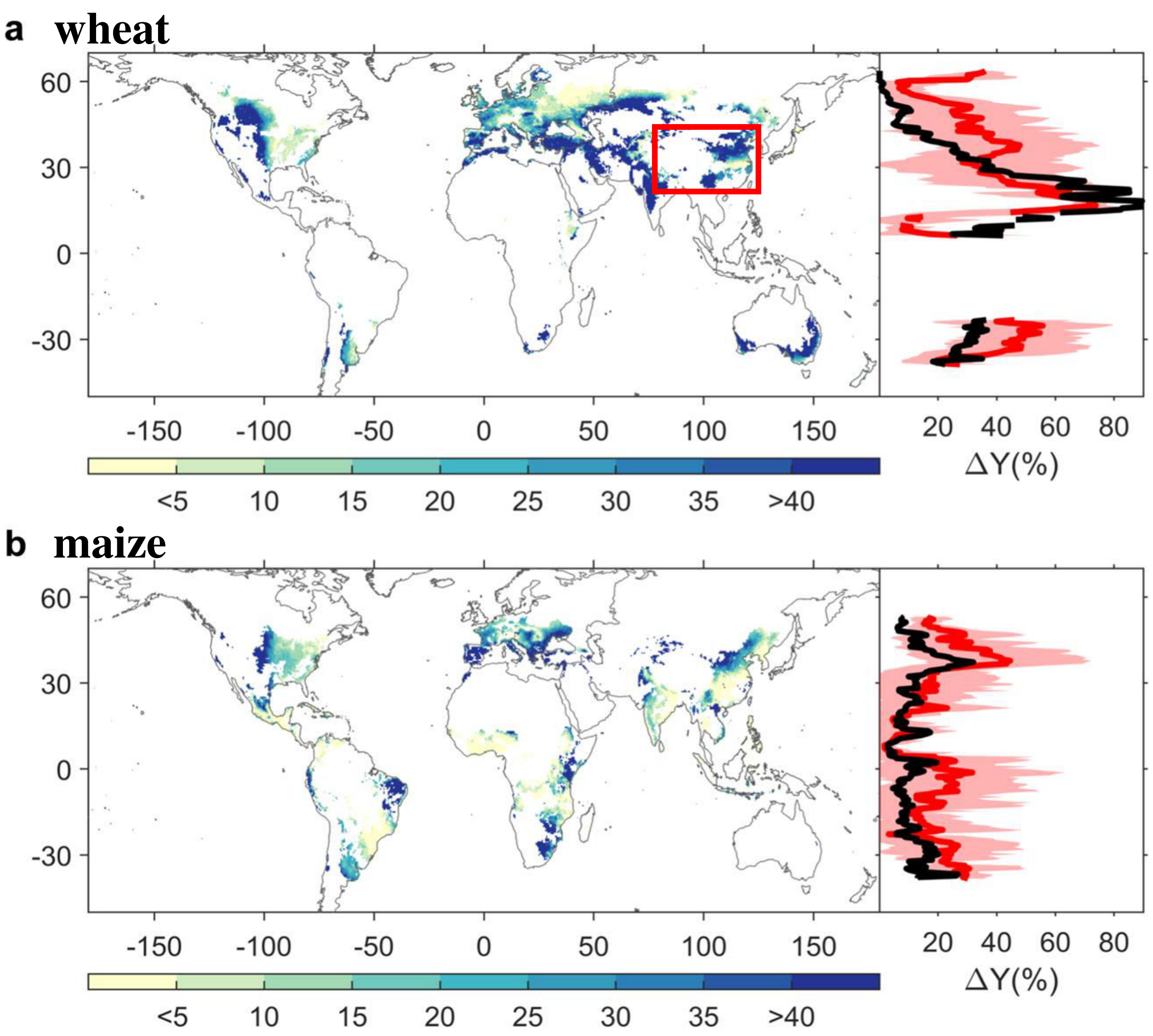
Effects of irrigation——Crop yields



Simulated maize yields for (a) irrigated and (b) rainfed cultivation

Liu et al. (2016, AFM)

Effects of irrigation——Crop production globally



$$\Delta Y = \frac{irrigated\ yield\ - rainfed\ yield}{irrigated\ yield}$$

At global scale, ΔY is
34 ± 9% for wheat
22 ± 13% for maize.

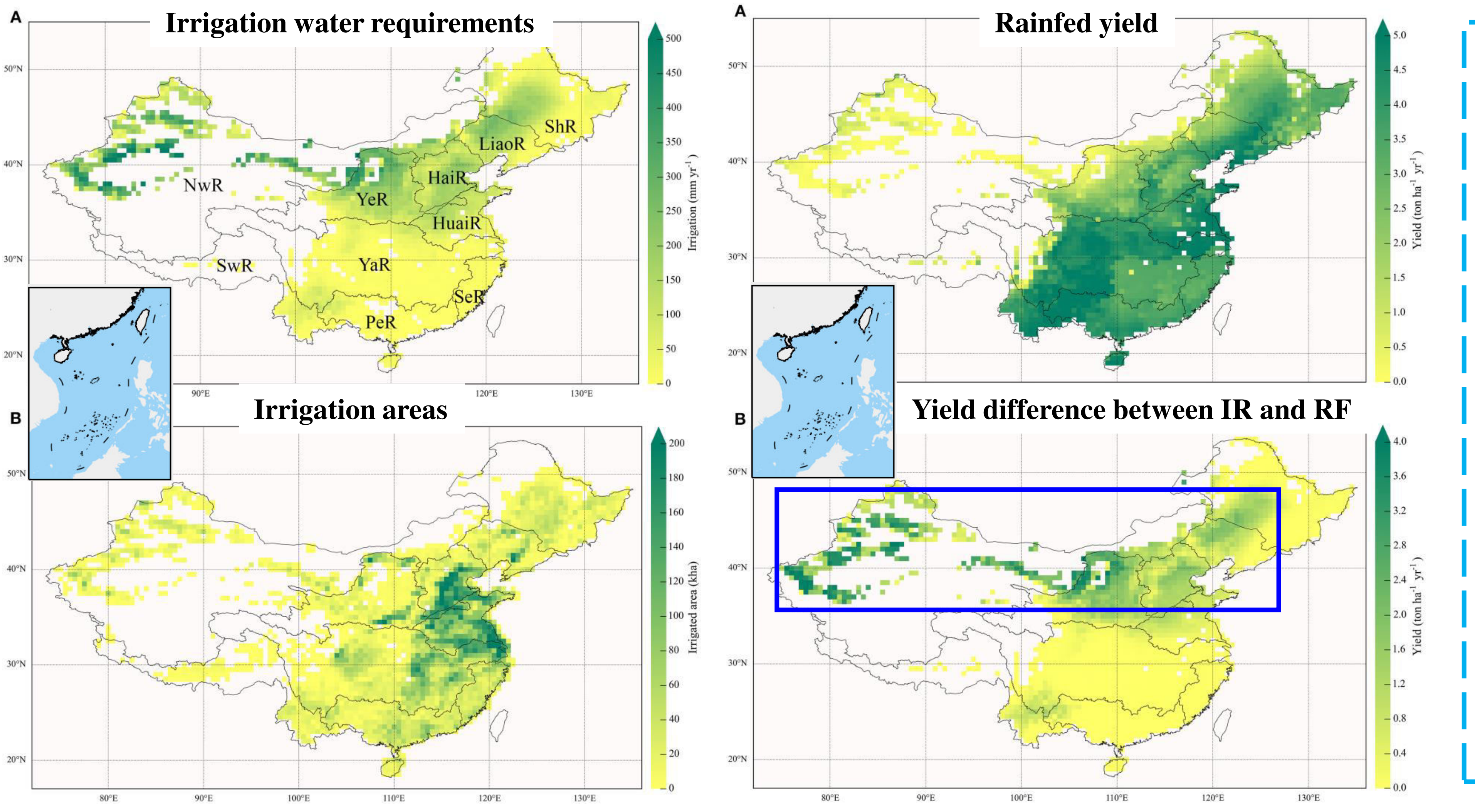
ΔY (%) in several major producers

Wheat		Maize	
China	42.2	USA	24.9
India	53.5	China	22.6
Russia	15.7	Brazil	22.2
USA	31.9	France	24.4

Wang, ..., Ciais, ..., Liu, et al.

(2020, Nat. Comm.)

Effects of irrigation——Crop production in China



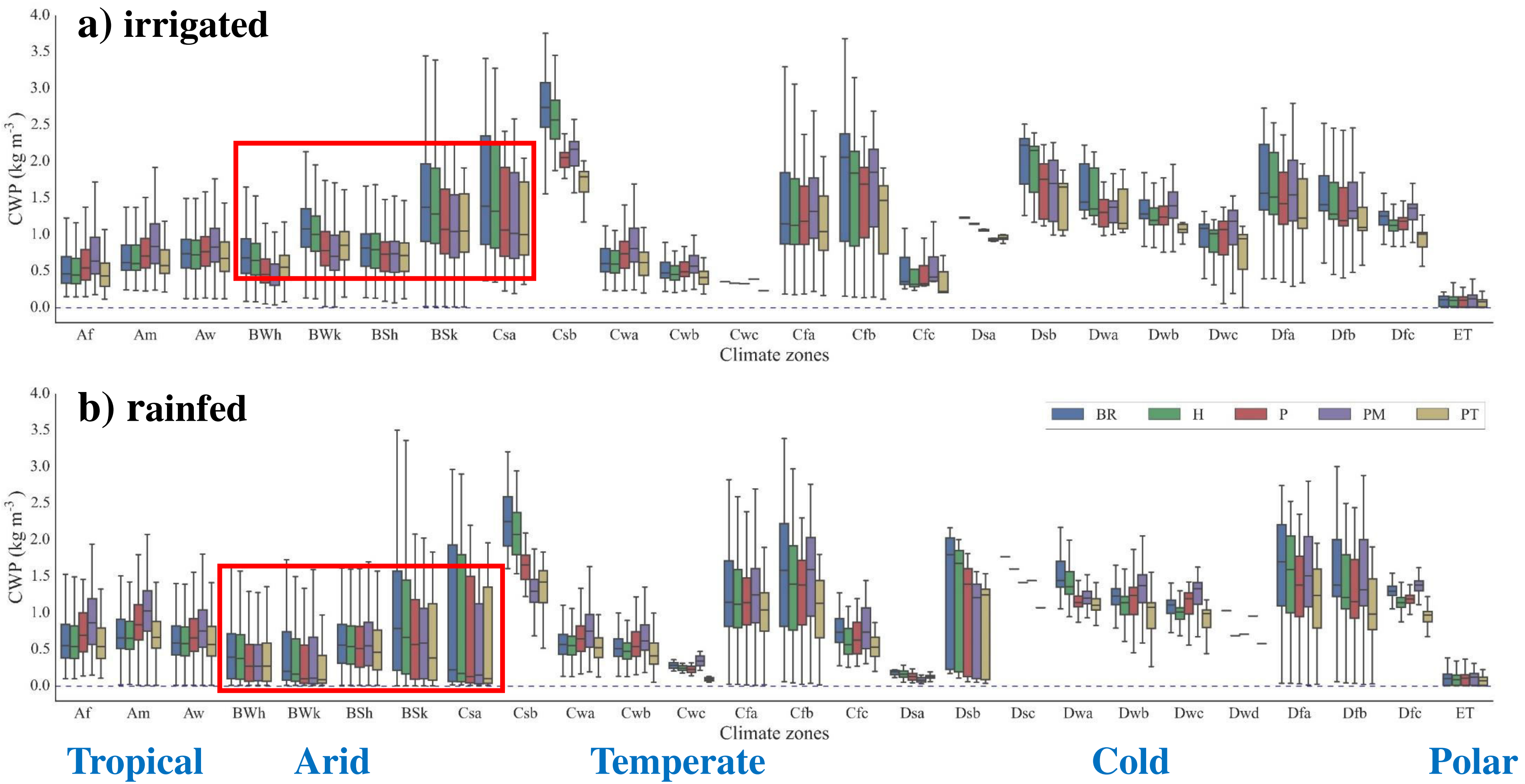
Liu et al. (2019, FES)

In China, there are high irrigation water requirements in northern China.

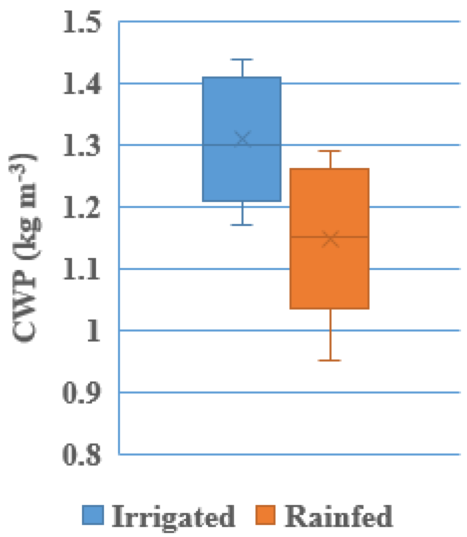
Therefore, irrigation could largely increase crop yields there.

Especially, irrigated crop yields could be more than 6 times higher than rainfed crop yields in northwestern China.

Effects of irrigation——Crop water productivity



$$CWP = \frac{yield}{ET}$$

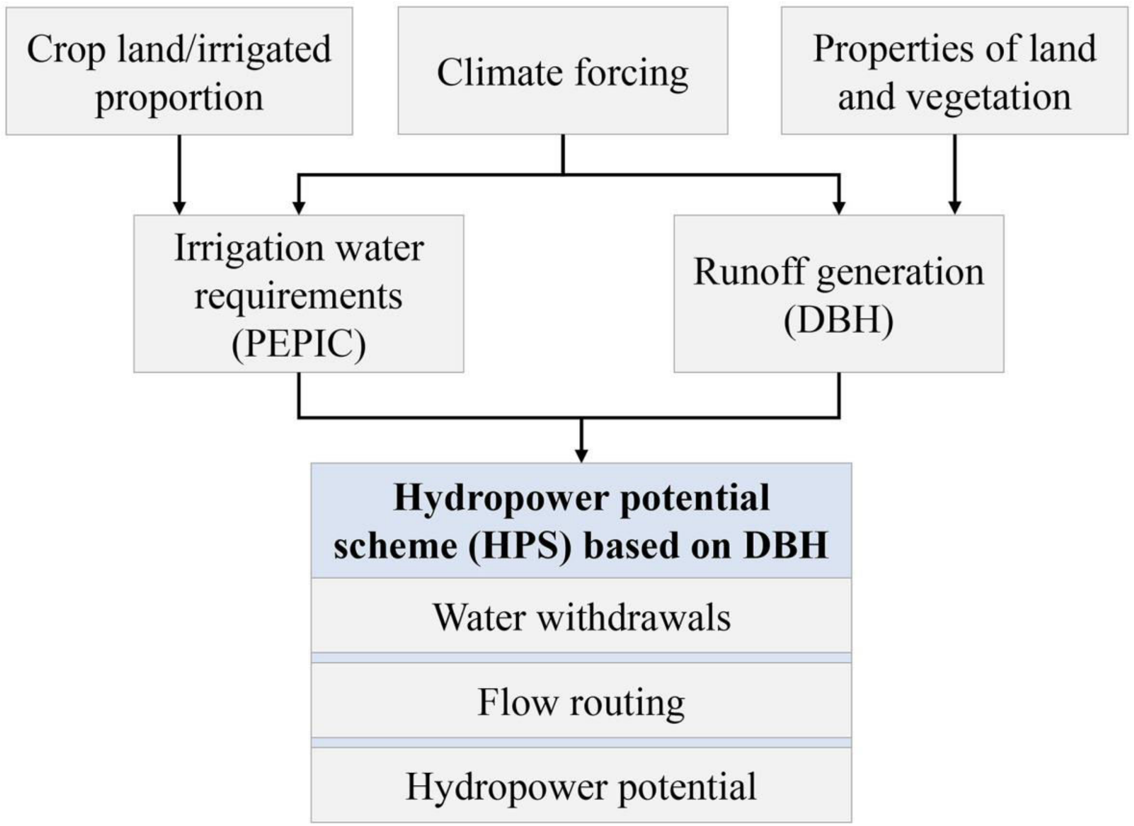


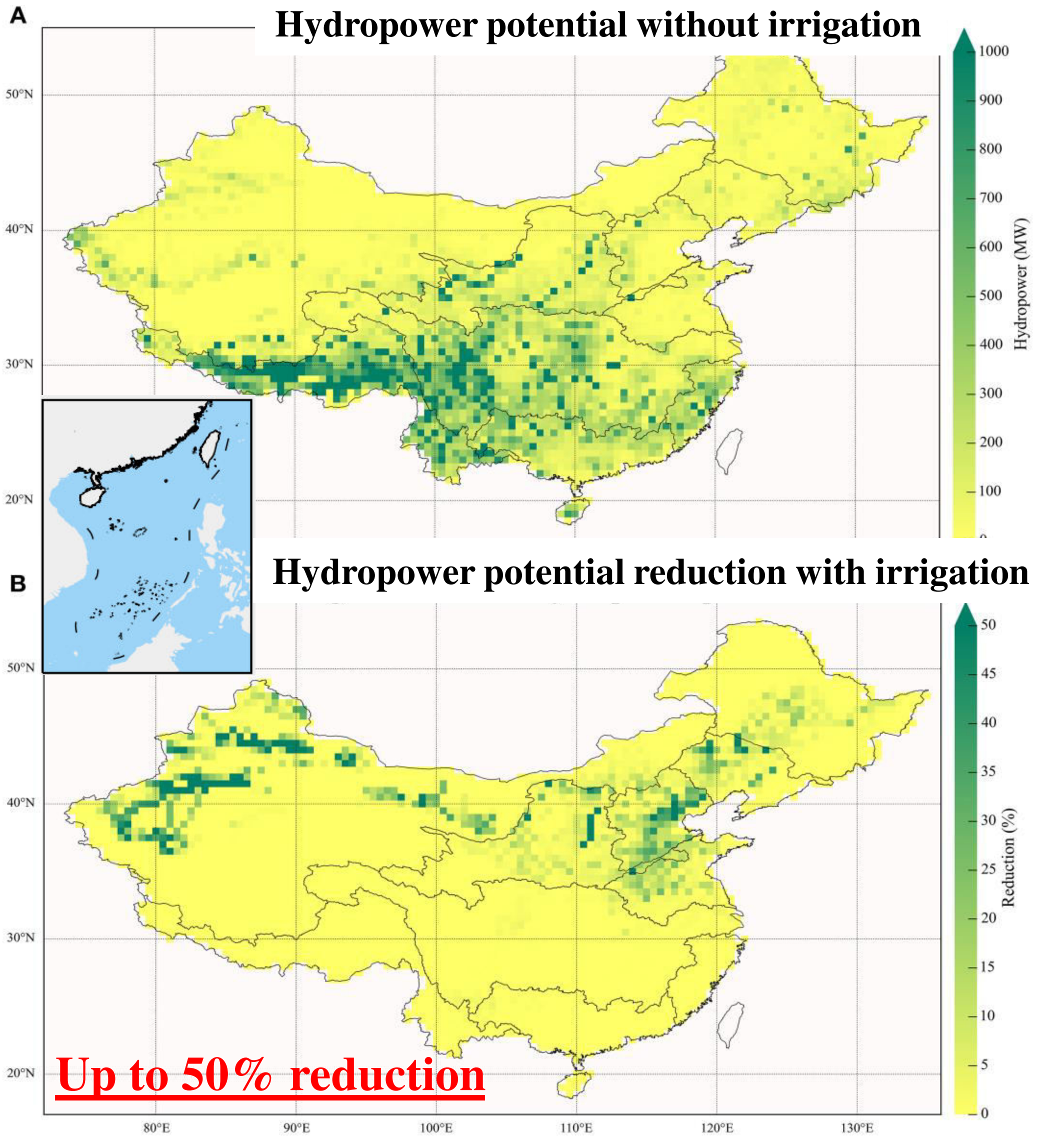
Nutrient: in 2000

Crop water productivity (CWP) for (a) irrigated and (b) rainfed cultivation

Liu et al. (2016, AFM)

Irrigation challenges——Water-food-energy nexus

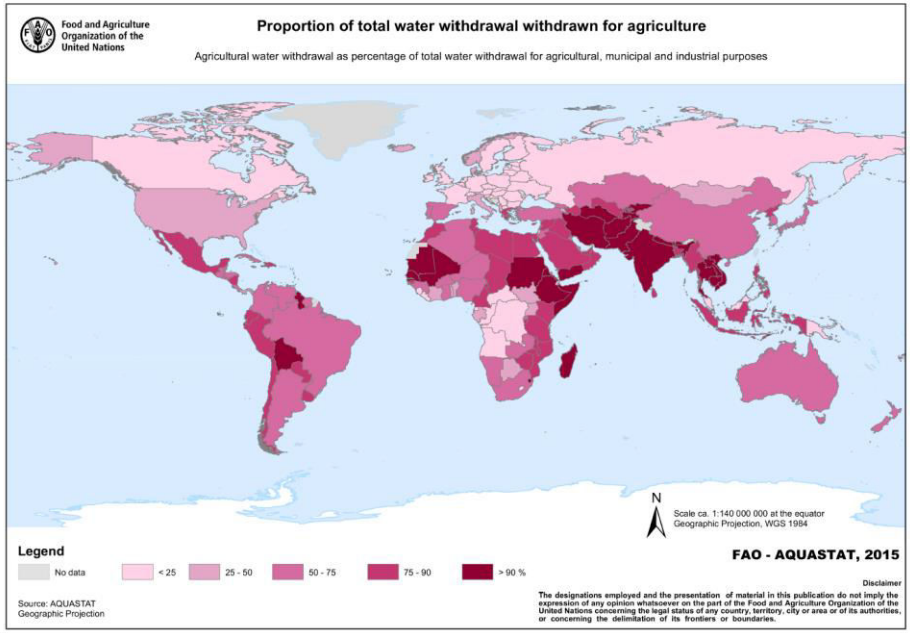


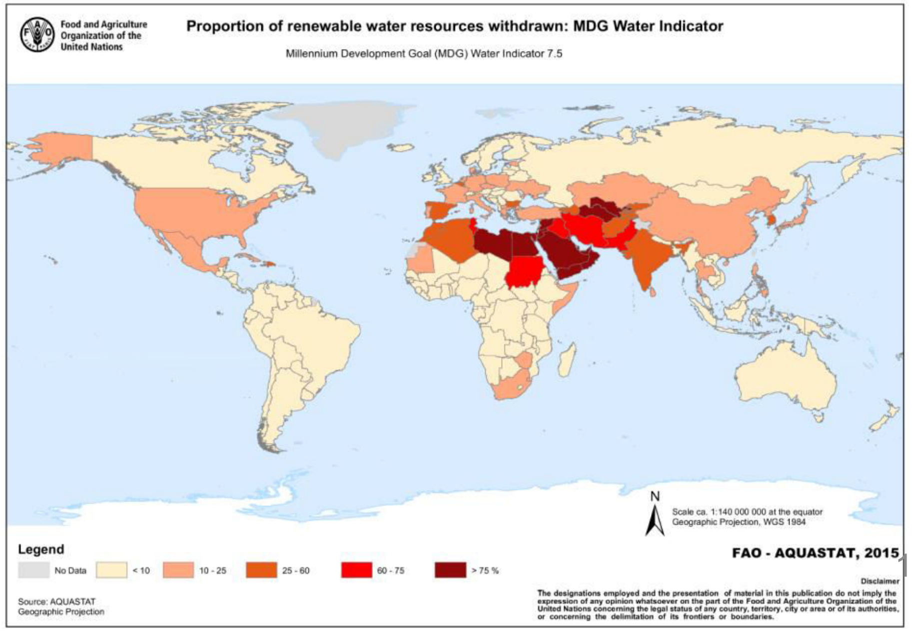


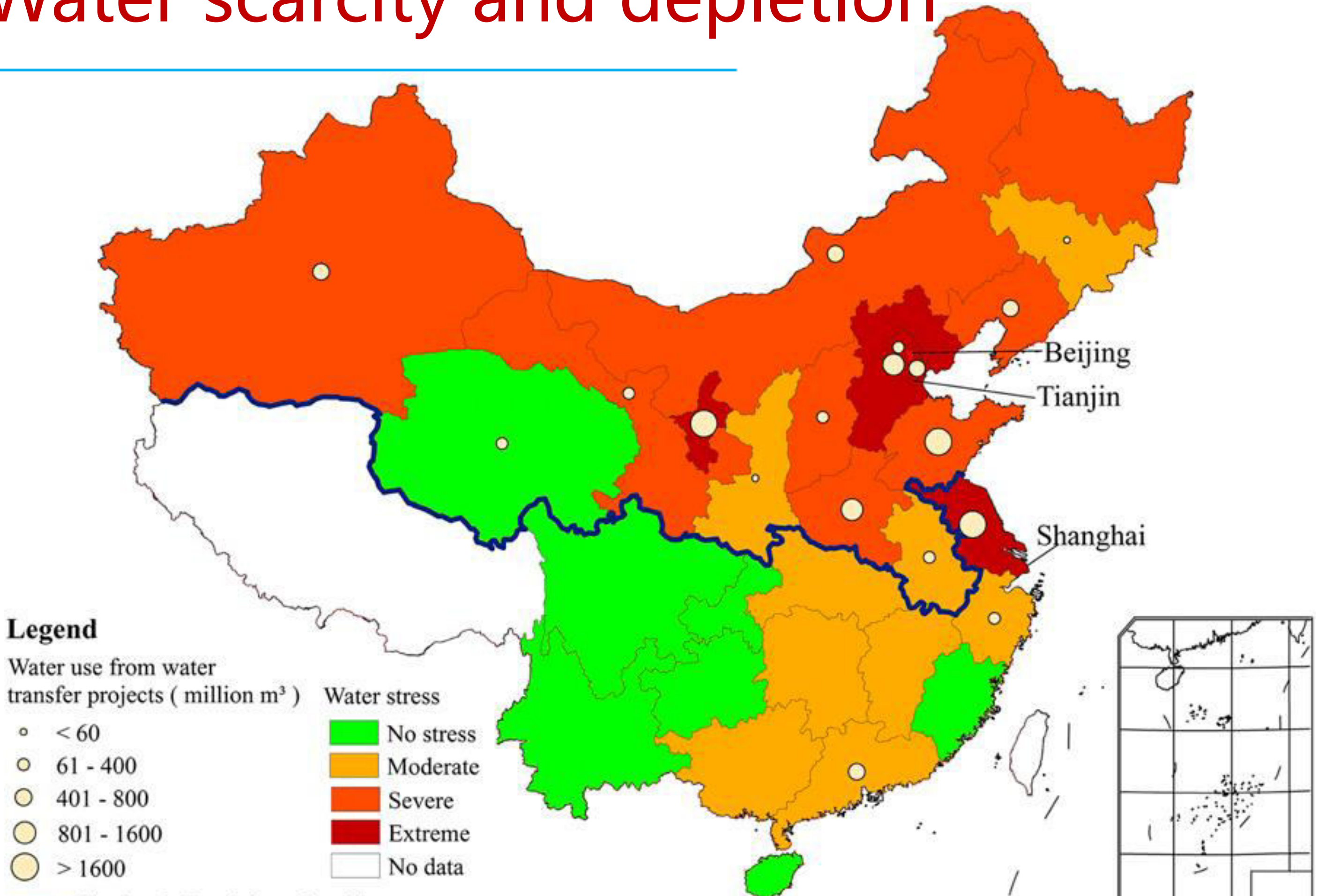
Liu et al. (2019, FES)

- ➢ **The DBH model was coupled with the PEPIC model to investigate the impacts of irrigation on hydropower potential.**

Irrigation challenges——Water scarcity and depletion







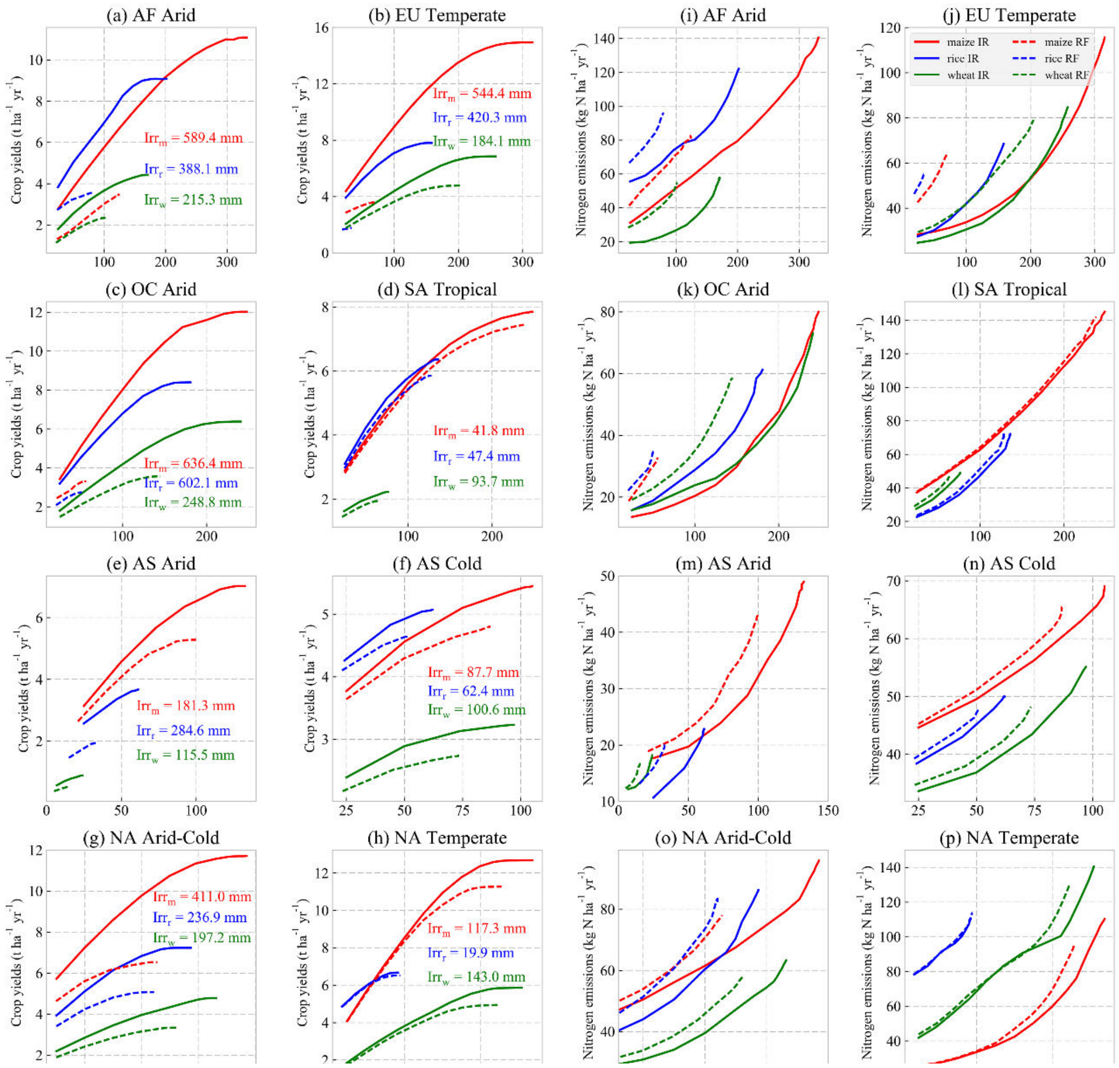
Zhao et al., (2015, PNAS)

Large proportion of water resources has been withdrawn for irrigation, resulting in severe water scarcity around the world.

It's urgent to address the **irrigation-related challenges**.

Irrigation challenges——Enlarging pollution

Crop yields **Nitrogen losses**

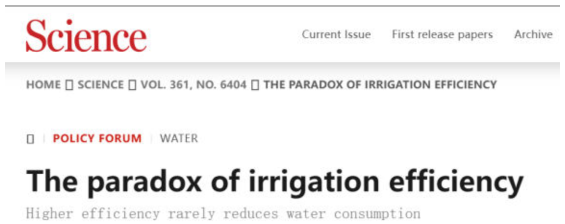


Liu et al. (2018, ES&T) **Nitrogen inputs**

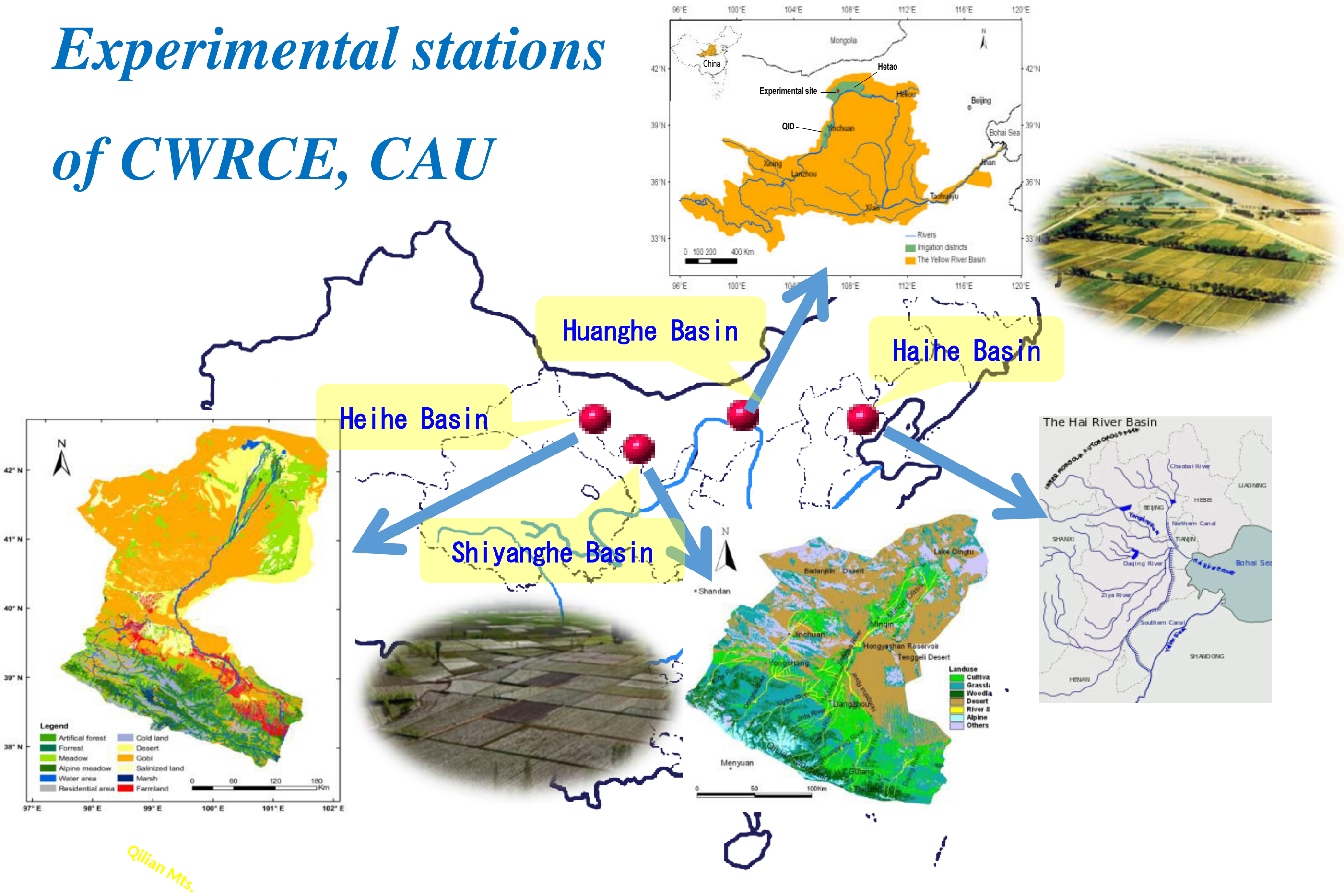
Effects of irrigation on crop yields and N losses:

- Irrigation enlarges the upper limits of effective N application;
- Irrigation significantly increases crop yield responses to N additions;
- Irrigated yields are much higher than rainfed yields in some arid and temperate regions without N limitation;
- Irrigation also reduces the response of N losses to N additions.

Lowering the impacts——Improving WUE

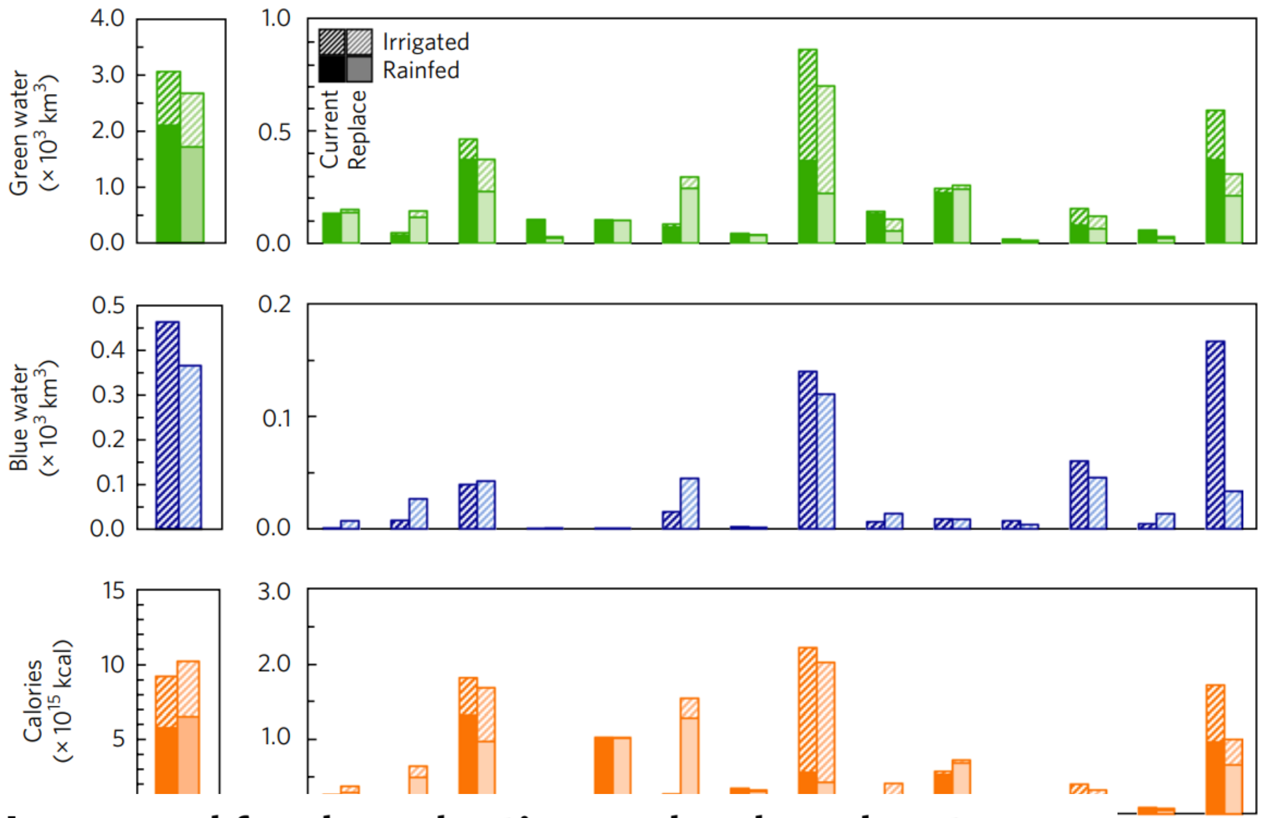


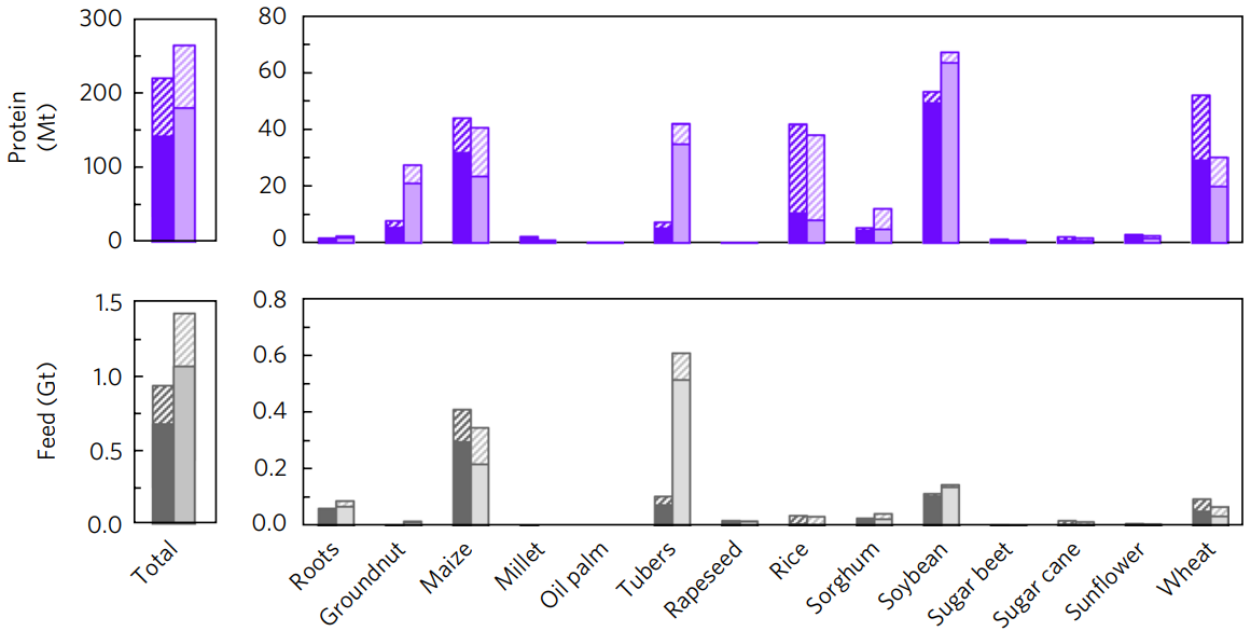
Experimental stations of CWRCE, CAU



- **Theory:**
  - Under <u>alternate partial root-zone irrigation</u>, water use can be reduced by 23% and WUE increased by 27% (*Kang et al., 2002; Du et al., 2006*)
  - <u>Regulated deficit irrigation</u> can improve WUE (+47%) without significant yield reduction (*Kang et al. 2000; Du et al. 2010*)
- **Engineering:**
  - <u>Integration of water and fertilizer</u> can significantly improve crop yield and reduce water and N loss (*Ran et al., 2017*)
  - <u>Drip irrigation under film mulching</u> can save water through reducing soil water evaporation (*Qin et al., 2018*)

Lowering the impacts——Cropland redistribution





Increased food production and reduced water use through optimized crop distribution

nature geoscience

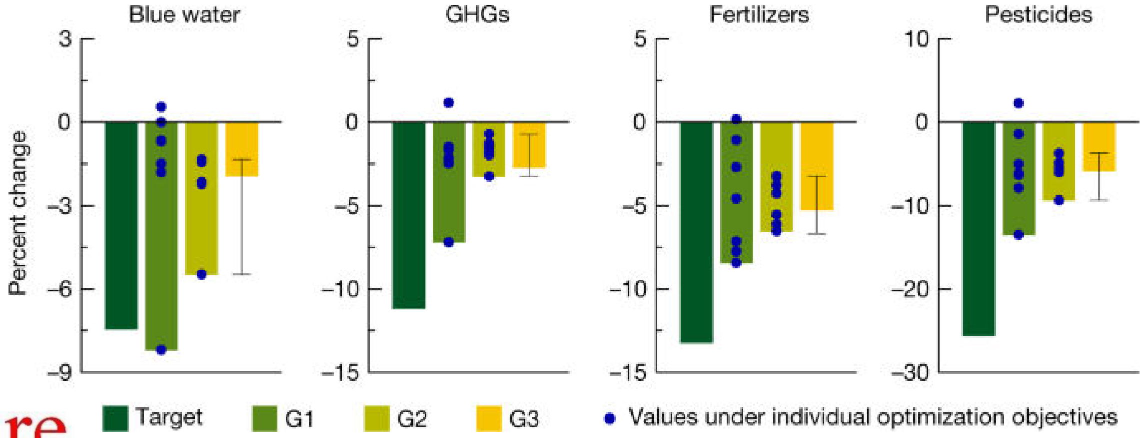
Kyle Frankel Davis[1,2,3]*, Maria Cristina Rulli[4], Antonio Seveso[4] and Paolo D'Odorico[1,5]

Article | Published: 16 March 2023

Crop switching can enhance environmental sustainability and farmer incomes in China

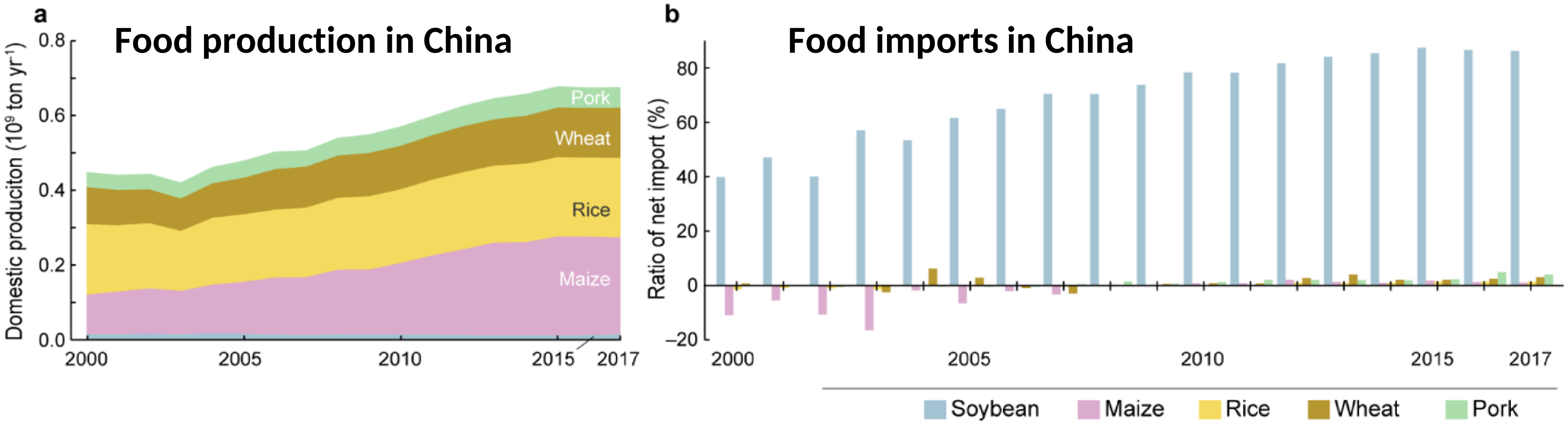
nature

Wei Xie, Anfeng Zhu, Tariq Ali, Zhengtao Zhang, Xiaoguang Chen, Feng Wu, Jikun Huang & Kyle Frankel Davis

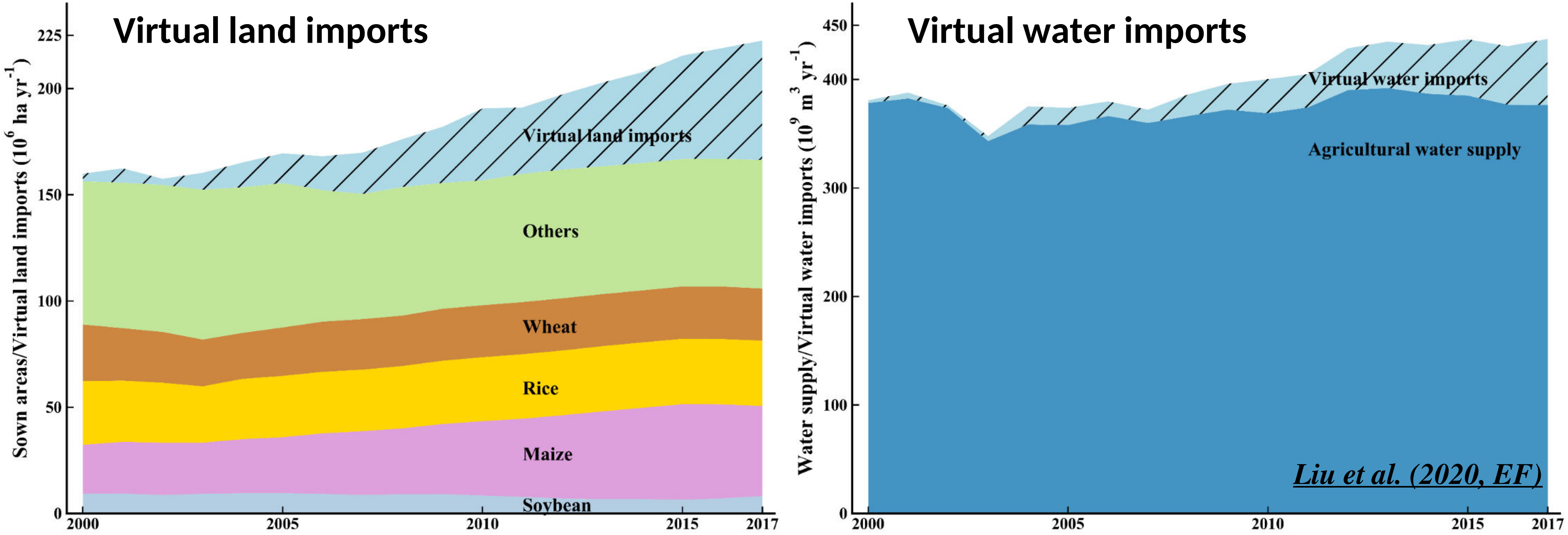


Realistic?

Lowering the impacts——Crop trade



Through trade, China imported a large amount of land and water virtually.



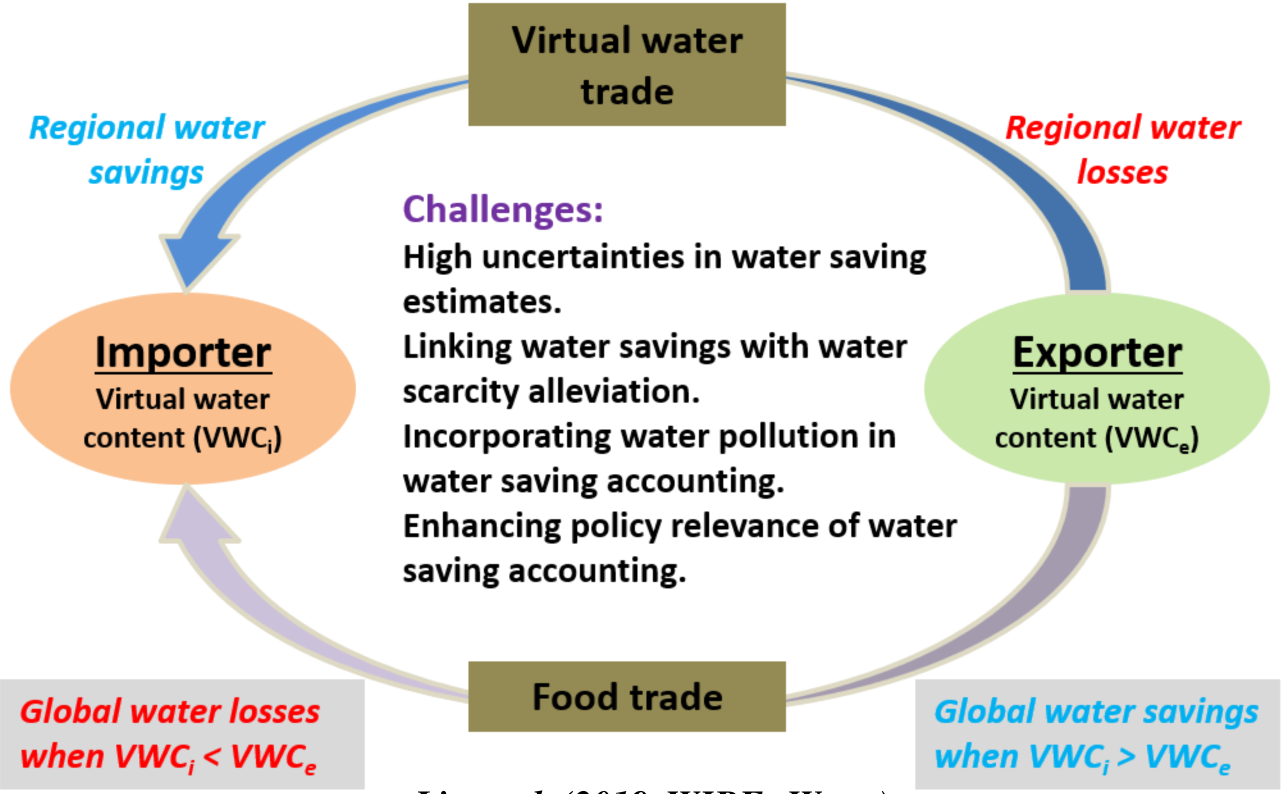
Land: 56 Mha in 2017

35% of total harvested land in China.

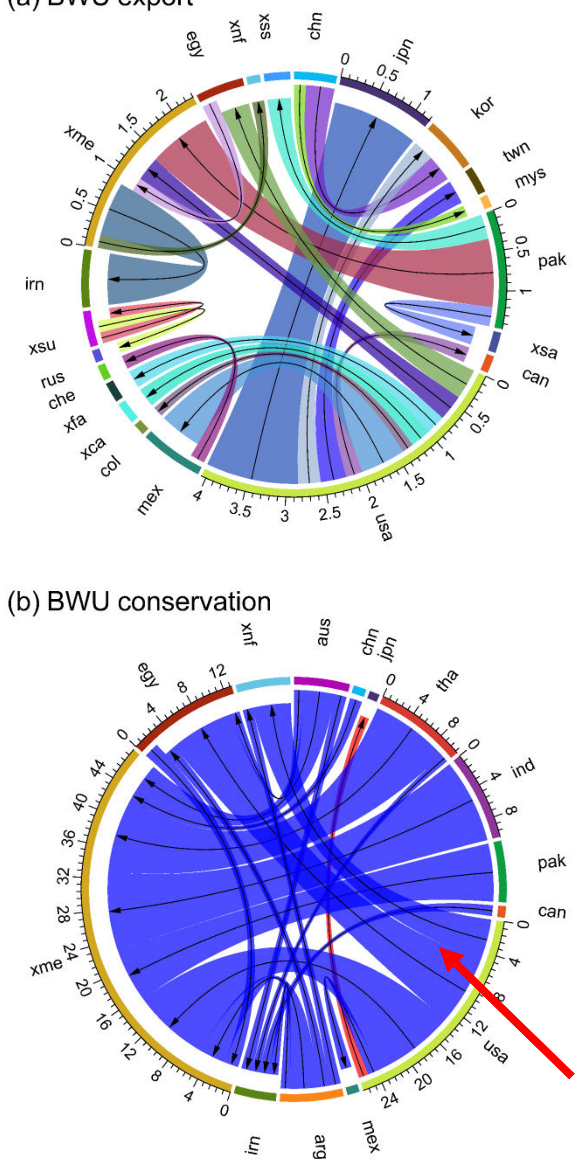
Water: 61 Gm^3 in 2017

16% of total agricultural water supply in China.

Lowering the impacts——Crop trade



Liu et al. (2019, WIREs Water)



Liu et al. (2018, STOTEN)

- **Blue water: growing season ET from irrigation**
- **There are regional water savings and global water savings associated with crop trade.**

Challenges:

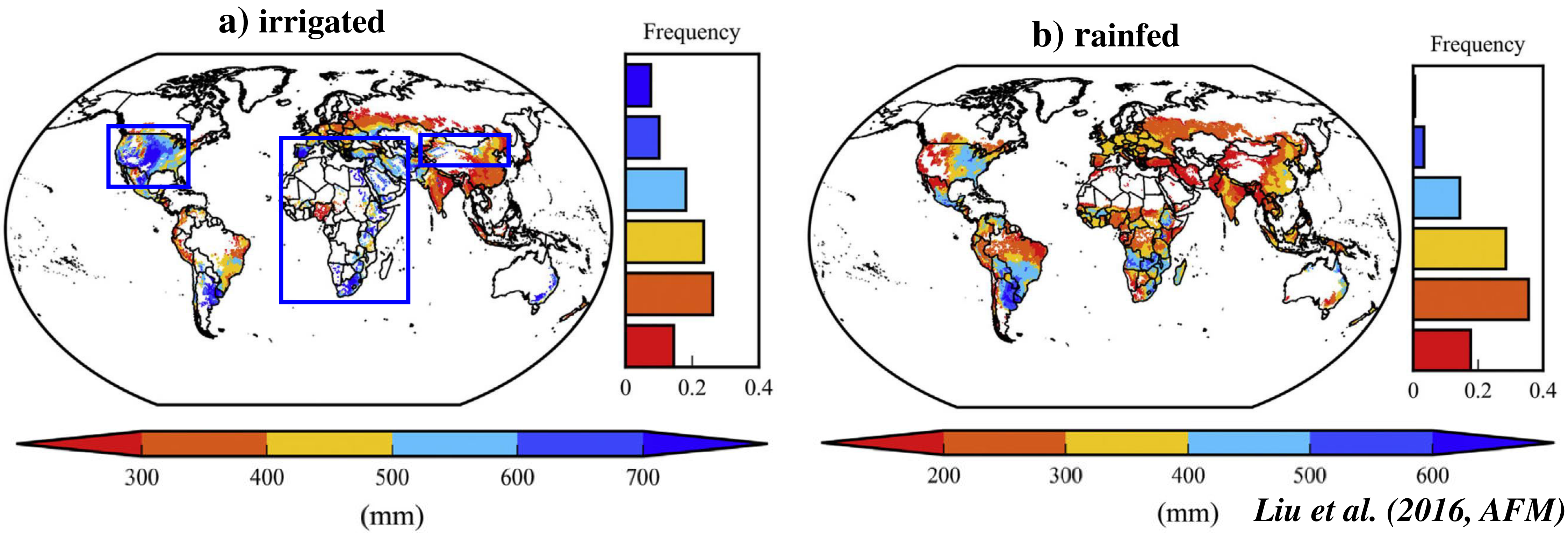
- ✓ Trade conflicts between countries;
- ✓ COVID-19;
- ✓ Self-sufficiency;
- ✓ Extreme climate;
- ✓ Unstable policies;
- ✓ Water depletion in exporting countries.

Blue color indicates water conservation.

Take-home messages

- Irrigation plays an essential role on increasing crop yields worldwide, but with various performances in different regions.
- Water withdrawal for irrigation also caused environmental issues, urgent to take measures to increase WUE and reduce irrigation water.
- In addition to traditional measures, international and interregional trade could also help deal with irrigation-related challenges, but facing challenges. The Belt and Road Initiative offers a good opportunity.

Effects of irrigation——growing season ET

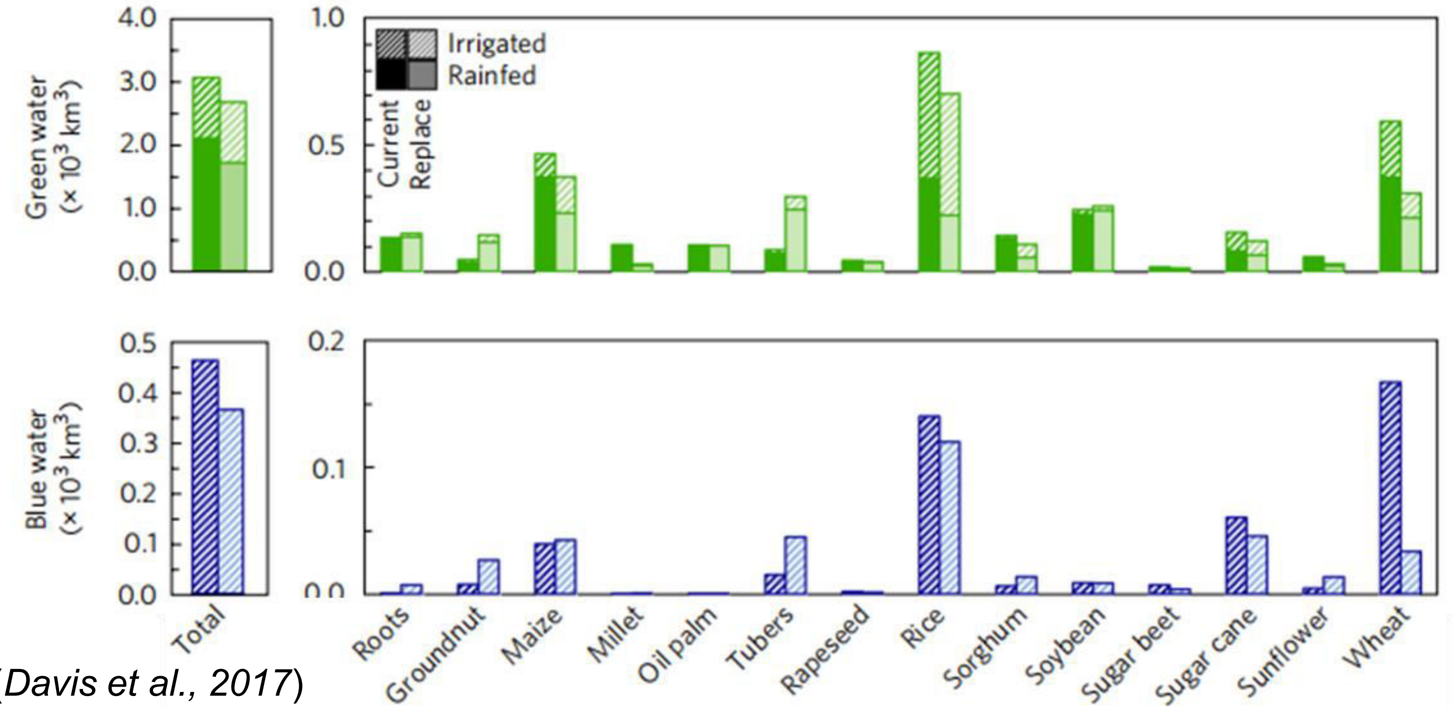


Liu et al. (2016, AFM)

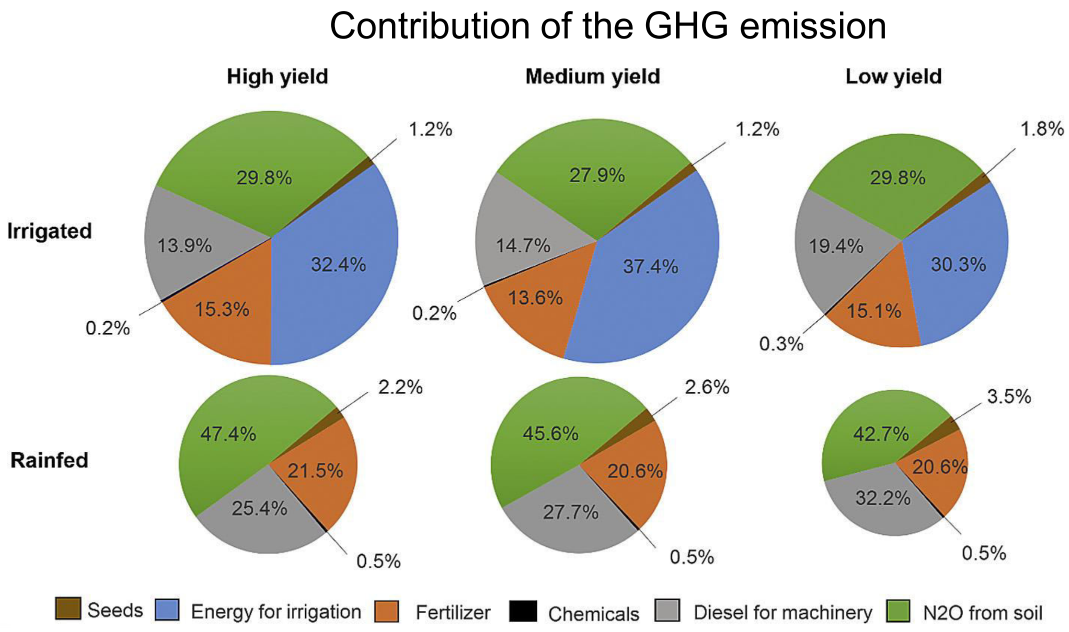
Growing season ET for maize under irrigated (a) and rainfed (b) cultivation

Three hotspot regions with significantly higher ET under irrigation cultivation compared to the ET under rainfed cultivation.

Introduction



(*Davis et al., 2017*)



(***Tahmasebi et al., 2018***)

- Current situation neither attains maximum production nor minimum water use. Reshaping the crops distribution and optimizing water management would save more than12% of water consumption (*Davis et al., 2017*).
- Compared with rainfed area, irrigated area obtained 22% higher yield, but produced 110% higher GHG emission and 62% higher carbon footprint (*Tahmasebi et al., 2018; Jamali et al., 2021*).

Studies on WUE at CAU

Long-term flux observation

Different irrigation methods experiment

WUE

⬆

Trade-off

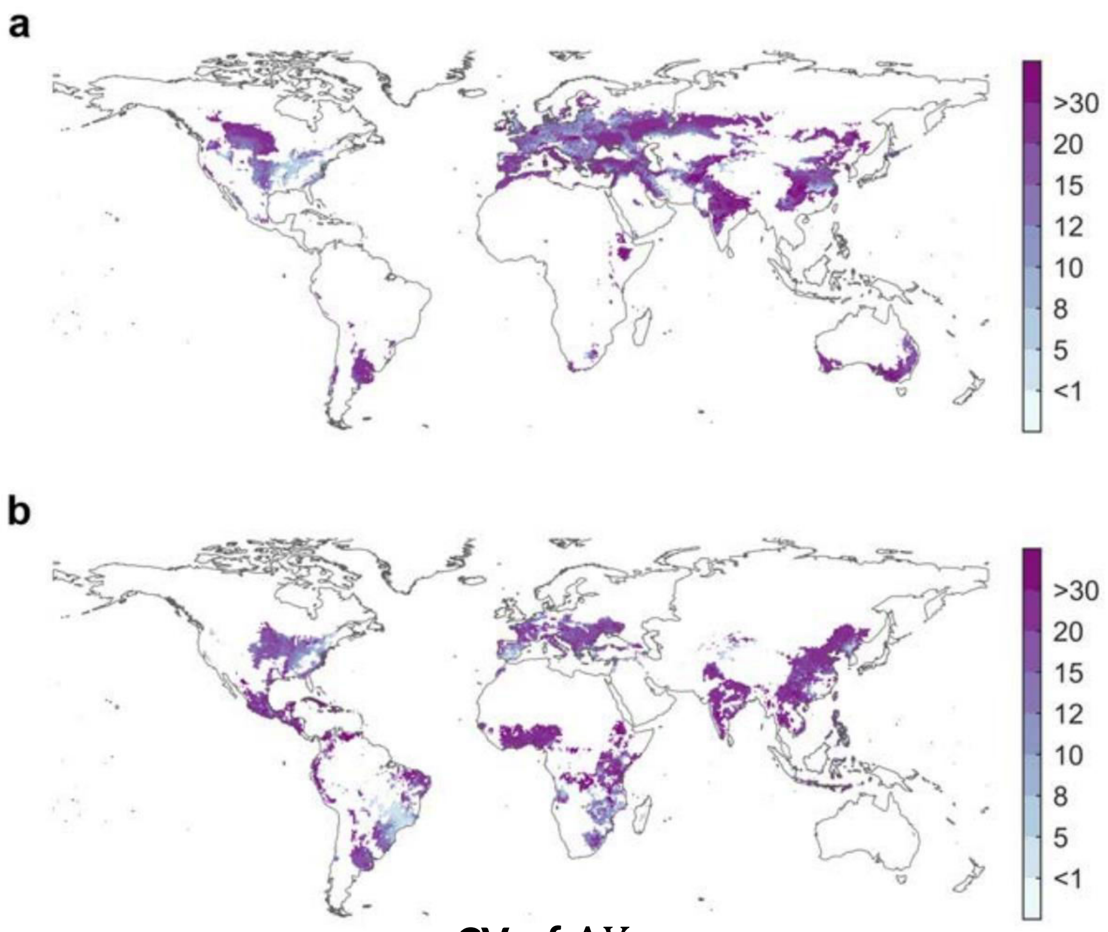
⬇

Yield

Long-term plastic film mulching experiment

Large weighing lysimeter observation

Contribution of irrigation to yields



CV of ΔY

Supplementary Table 4. Web links to GGCMI model output

Model	Wheat	Maize
EPIC-BOKU	http://dx.doi.org/10.5281/zenodo.1404761	http://dx.doi.org/10.5281/zenodo.1404767
EPIC-IIASA	http://dx.doi.org/10.5281/zenodo.1403195	http://dx.doi.org/10.5281/zenodo.1403203
EPIC-TAMU	http://dx.doi.org/10.5281/zenodo.1409013	http://dx.doi.org/10.5281/zenodo.1409009
GEPIC	http://dx.doi.org/10.5281/zenodo.1408571	http://dx.doi.org/10.5281/zenodo.1408577
LPJ-GUESS	http://dx.doi.org/10.5281/zenodo.1408623	http://dx.doi.org/10.5281/zenodo.1408647
LPJmL	http://dx.doi.org/10.5281/zenodo.1403013	http://dx.doi.org/10.5281/zenodo.1403073
ORCHIDEE-crop	http://dx.doi.org/10.5281/zenodo.1408191	http://dx.doi.org/10.5281/zenodo.1408199
pAPSIM	http://dx.doi.org/10.5281/zenodo.1403183	http://dx.doi.org/10.5281/zenodo.1403189
pDSSAT	http://dx.doi.org/10.5281/zenodo.1403171	http://dx.doi.org/10.5281/zenodo.1403181
PEGASUS	http://dx.doi.org/10.5281/zenodo.1409546	http://dx.doi.org/10.5281/zenodo.1409550

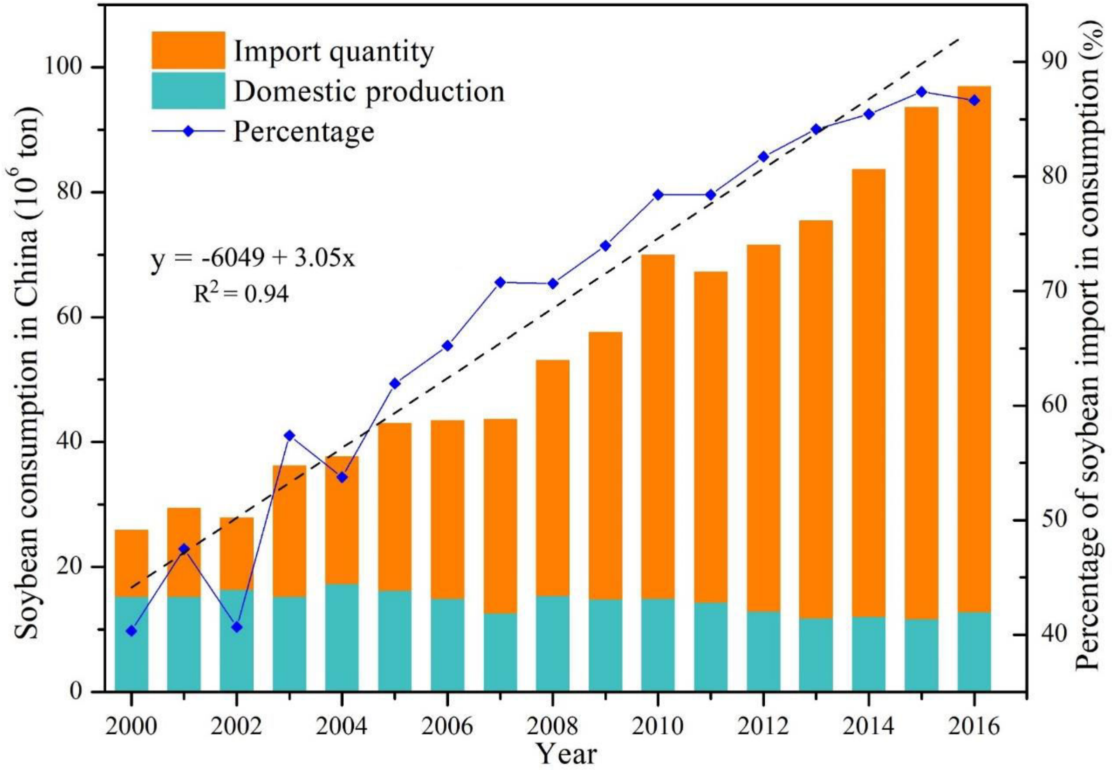
High level of CV of across 10 large-scale crop models

Wang, ..., Ciais, ..., Liu, et al.

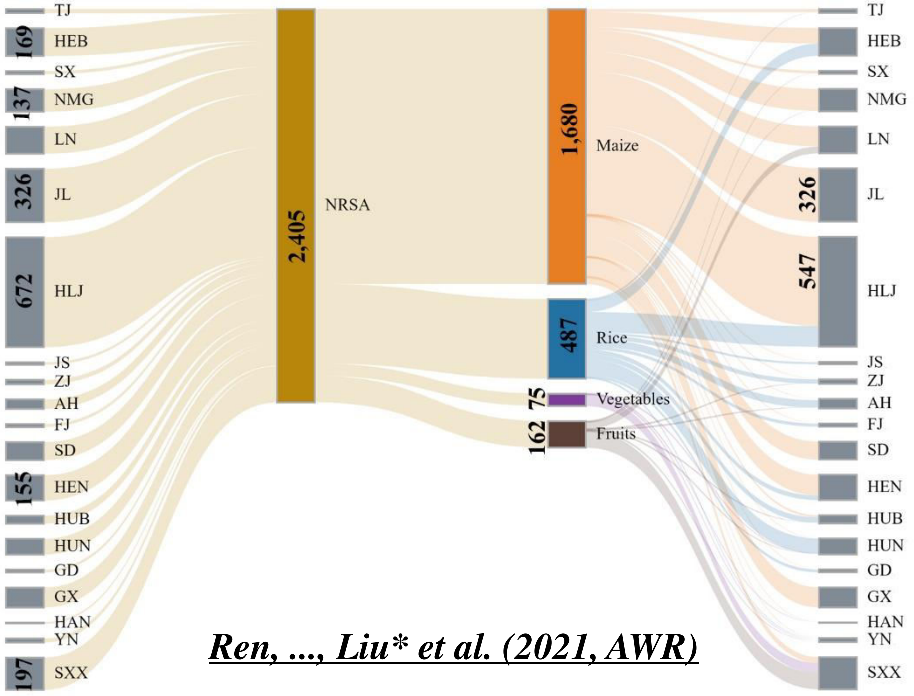
(2020, Nat. Comm.)

Effects of trade on China's water security

- Soybean production has decreased since 2004.
- Soybean imports increased dramatically, even reached 100 million tons in 2020.
- The soybean areas was transferred to other crops: maize, rice, vegetables, and fruits.



Soybean production and import in China



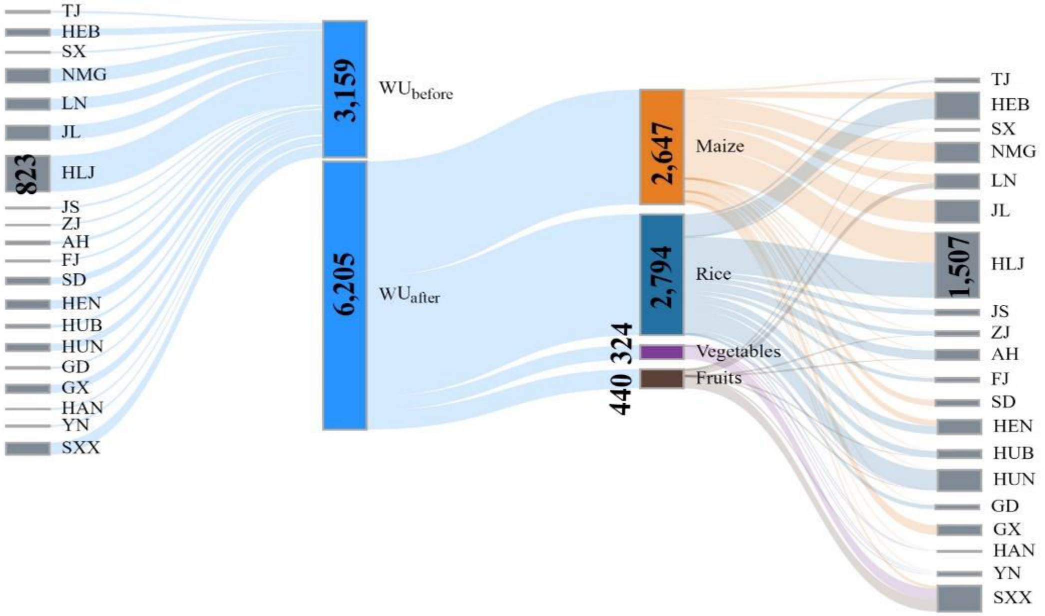
Ren, ..., Liu et al. (2021, AWR)*

Conversation of soybean land to other crops

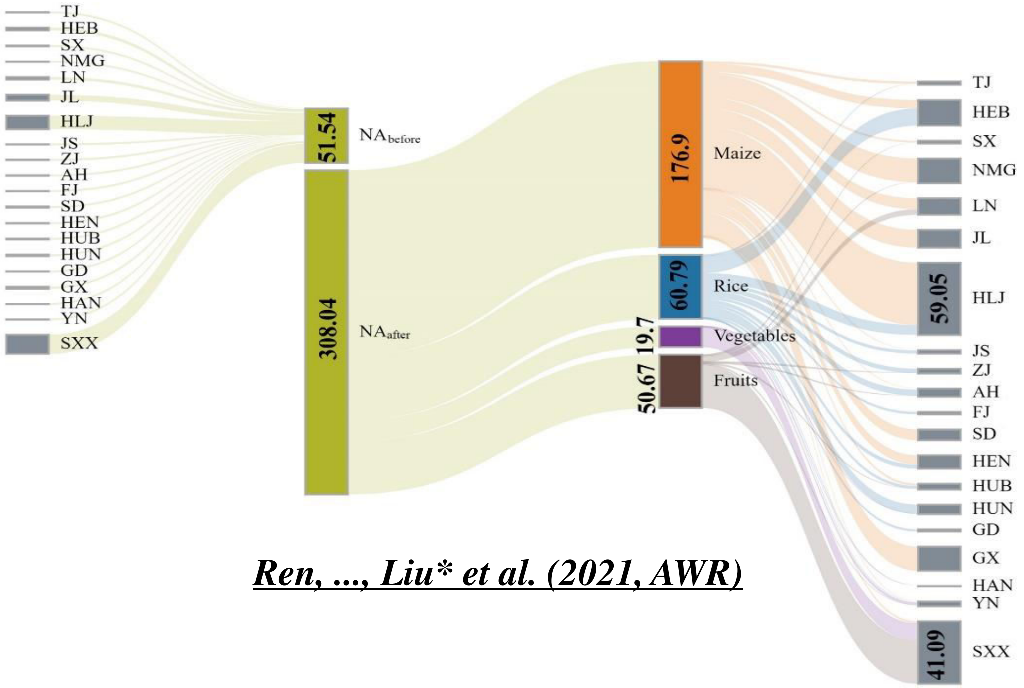
Effects of trade on China's water security

Due to the conversion of soybean production to other crops:

- ✓ Water uses **doubled after the conversion**;
- ✓ Nitrogen uses **increased by 5 times**.



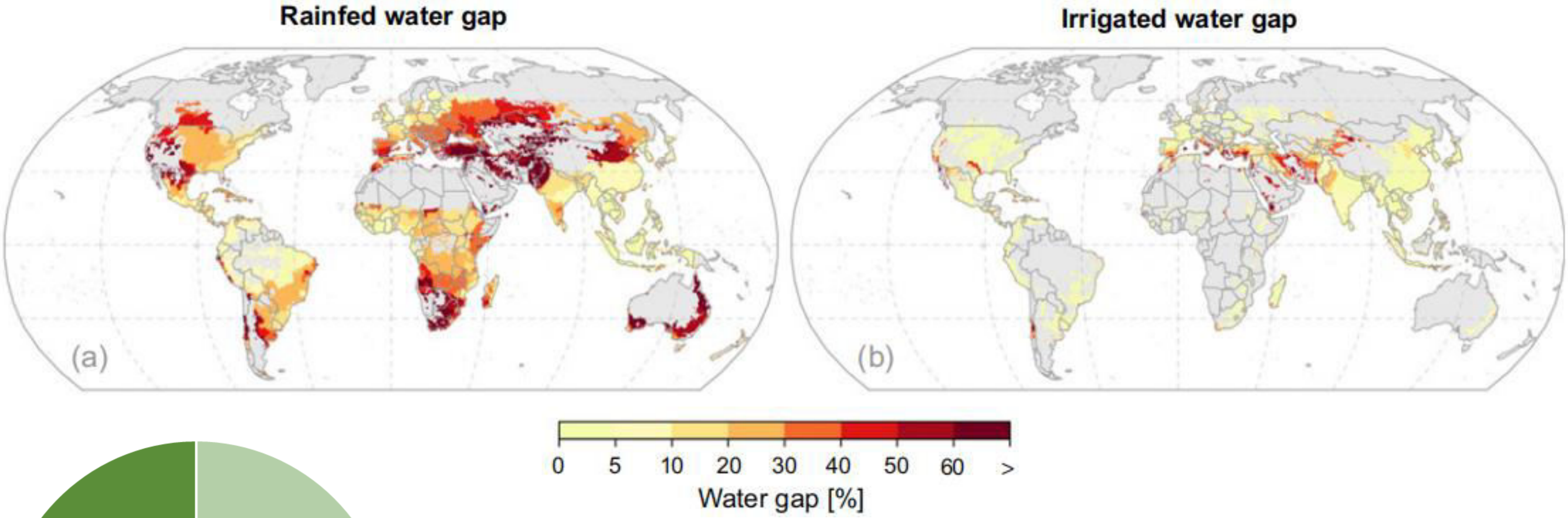
Water uses for soybean and other crops

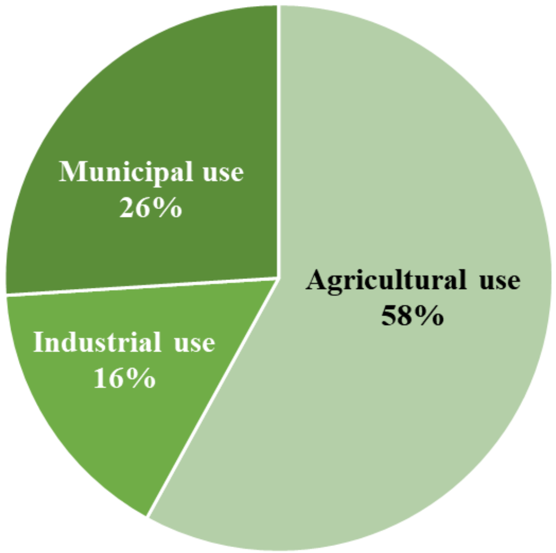


Ren, ..., Liu et al. (2021, AWR)*

Nitrogen uses for soybean and other crops

Introduction





(FAOSTAT, 2020)

- Agricultural water use is the main source of water withdrawals, accounting for around 60% of all the world's water withdrawals (*FAOSTAT, 2020*).
- The global total irrigation area is around **371.7 million ha**, **78% of which** are concentrated in developing countries and emerging economies (*FAOSTAT, 2020*).