Paris 2025

Comment adapter les systèmes de culture à l'augmentation de la concentration de CO_2 et au changement climatique ?

David Makowski

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Outline

- Why climate change is important for food security?
- How to study the impact of climate change on crop production and identify adaptation strategies?
- How to adapt cropping systems to climate change?

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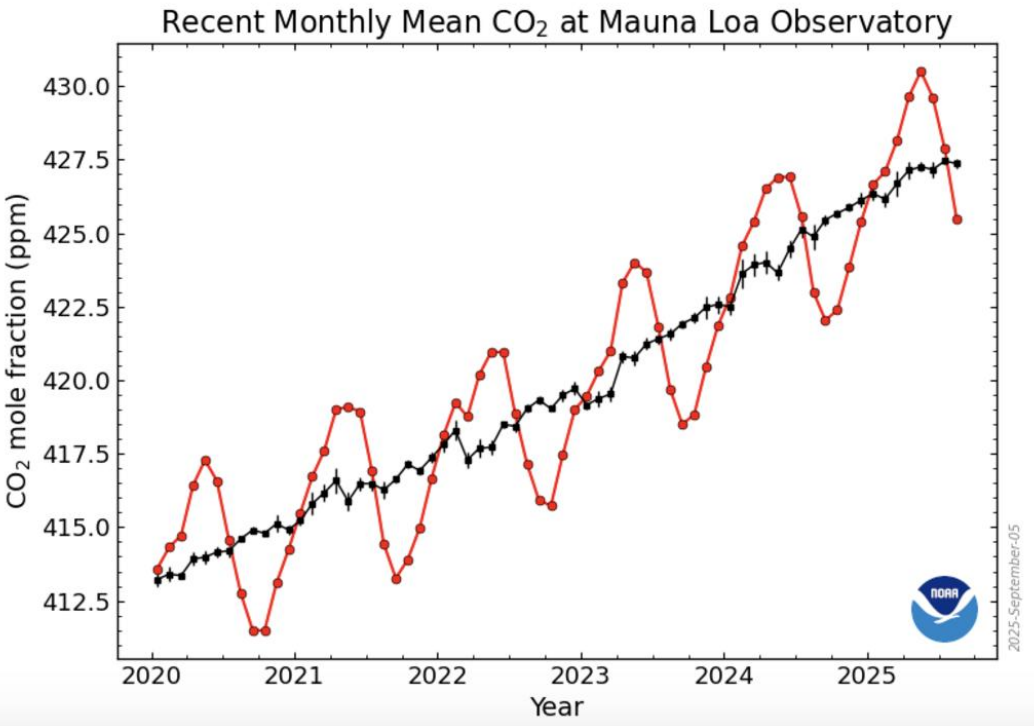
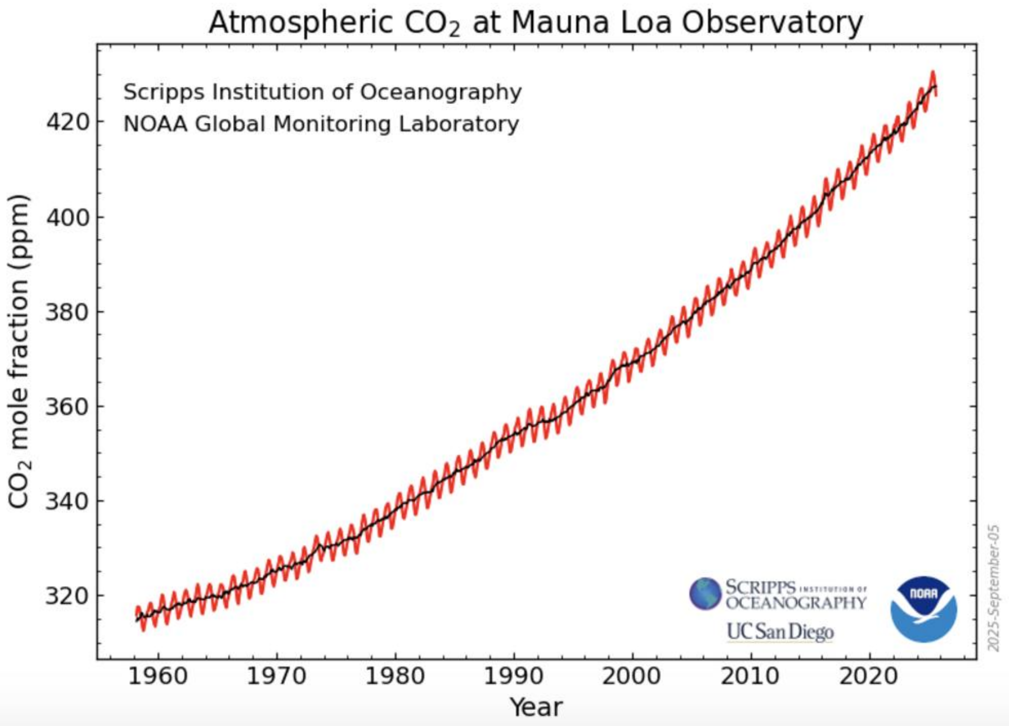
Monthly Average Mauna Loa CO_2

August 2025: 425.48 ppm
August 2024: 422.99 ppm
Last updated: Sep 05, 2025





Greenhouse gas concentration

Direct effect on photosynthesis

Harvest

Greenhouse gas concentration

Climate

Weather

- Temperature
- Rainfall
- ETP

Etc.

Harvest

United Nations
Convention to Combat
Desertification

DROUGHT IN NUMBERS 2022

« The number and duration of droughts has increased by 29 percent since 2000 »

Countries affected by drought in 2020-2022

https://www.unccd.int/resources/publications/drought-numbers

2018

News
09.07.2018
Lesedauer ca. 4 Minuten
Drucken
Teilen

DÜRRE IN DEUTSCHLAND 2018

Gibt es einen neuen Jahrhundertsommer?

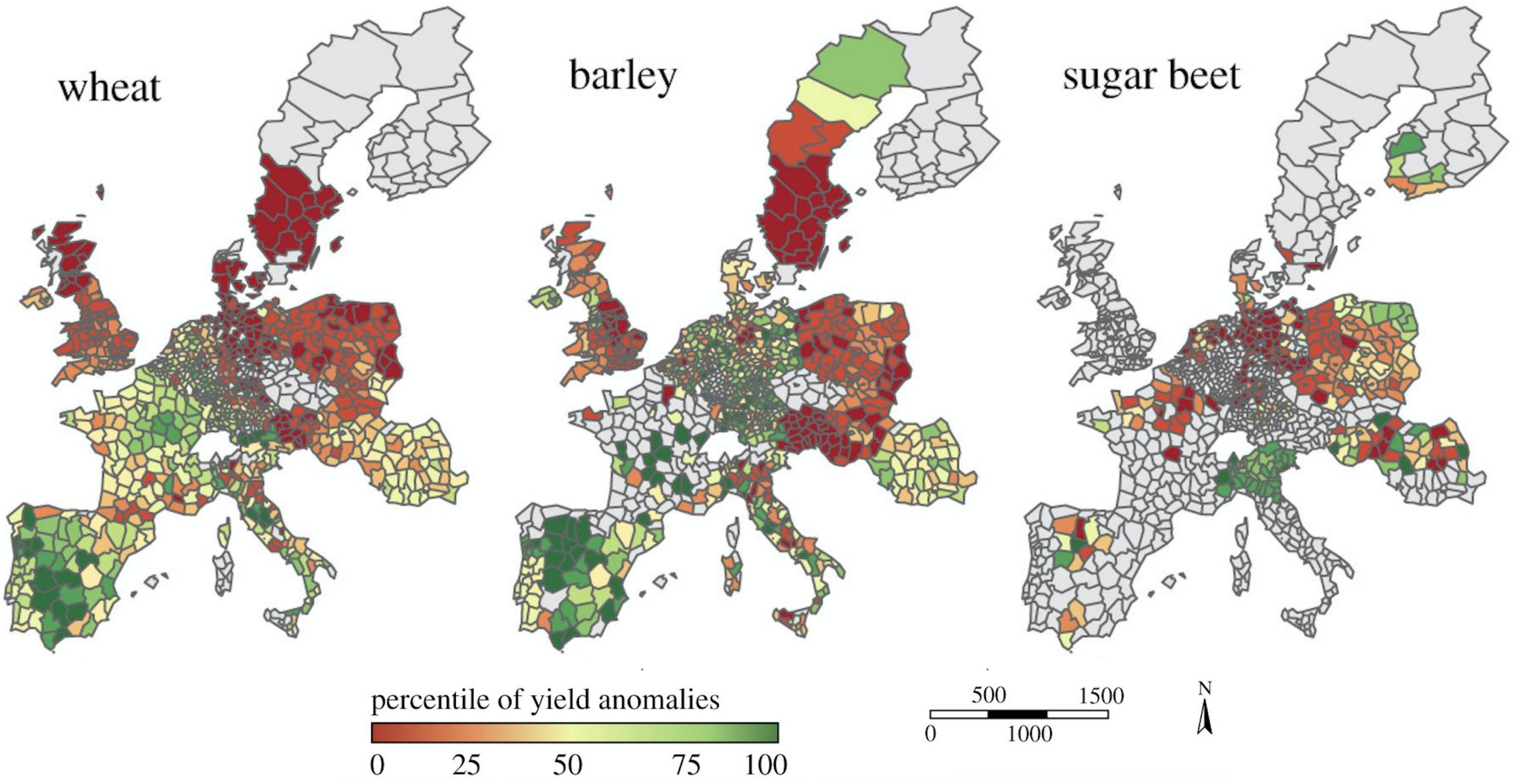
Die Trockenheit ist nicht so spektakulär wie Sturzfluten - richtet jedoch immense Schäden an. Dabei sind Dürreperioden in Deutschland gar nicht so selten.

von Lars Fischer

© MARCCOPHOTO / GETTY IMAGES / ISTOCK (AUSSCHNITT)

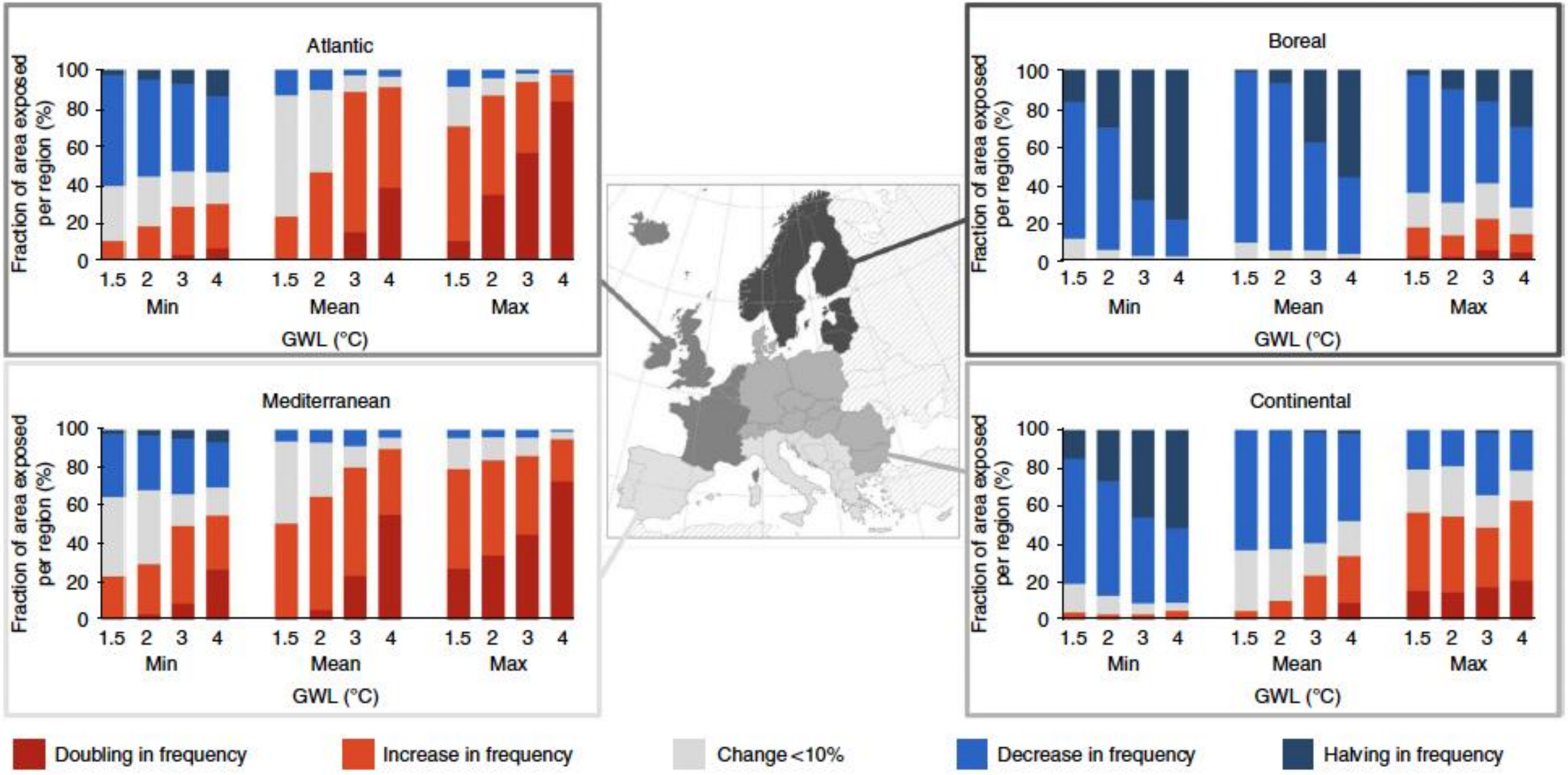
Yield losses and gains in 2018 in Europe

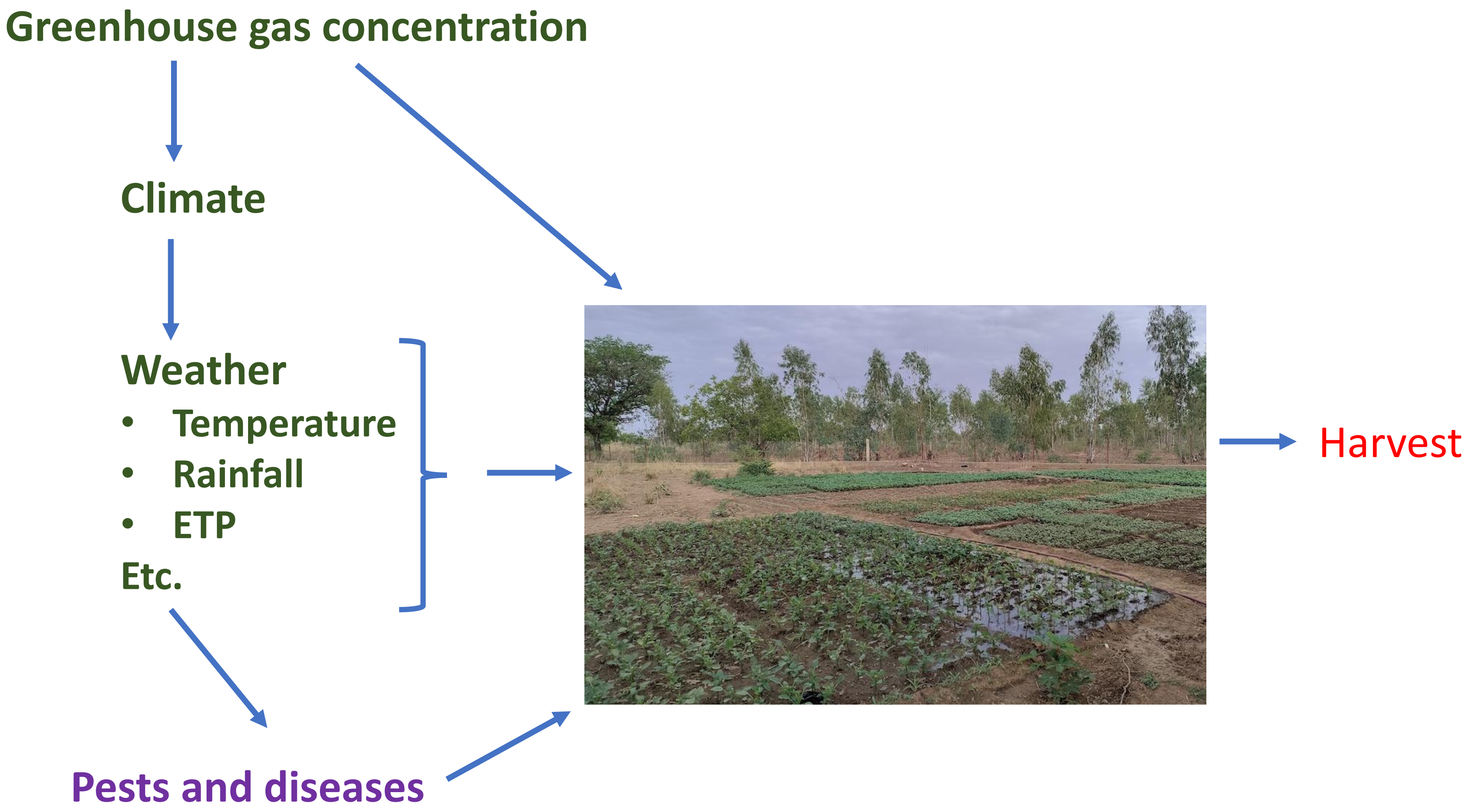
https://doi.org/10.1098/rstb.2019.0510



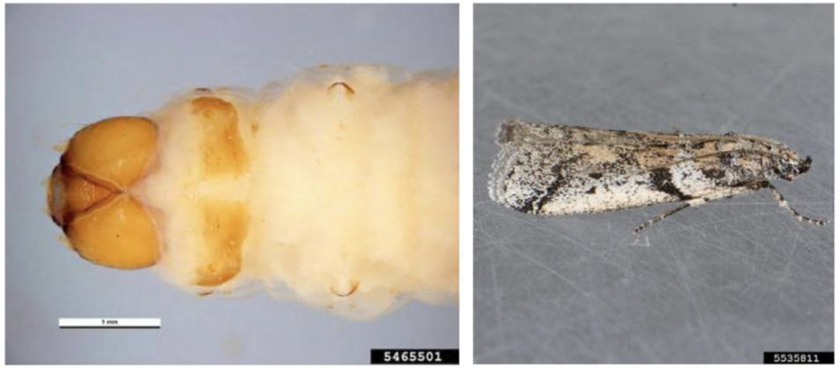
Projected increase of exposure to drought in Europe

https://doi.org/10.1038/s41558-021-01044-3




Greenhouse gas concentration
Climate
Weather
Temperature
Rainfall
ETP
Etc.
Pests and diseases
Harvest

Effect of climate change on the agro-climatic zones suitable for *Amyelois transitella*



a. Larva (Pest and Diseases Image Library, Bugwood.org) b. Adult (Mark Dreiling, Bugwood.org)

Figure 1: *Amyelois transitella* larva and adult (both illustrations under a Creative Commons Attribution-Noncommercial 3.0 License)

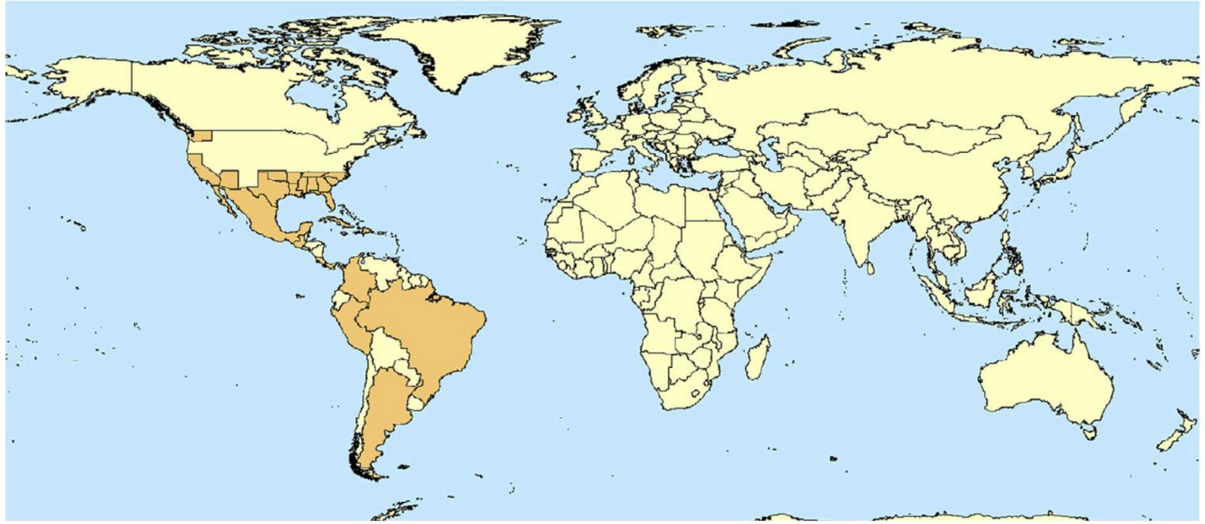
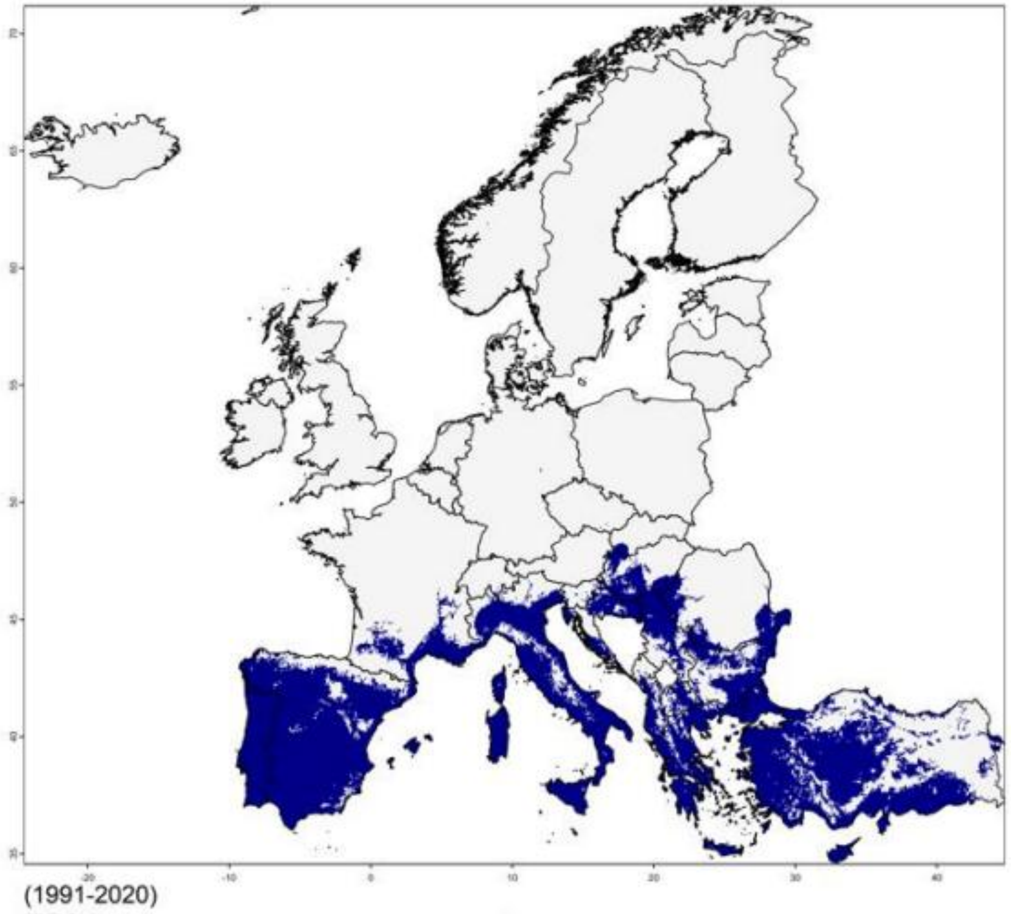


Figure 2: Global distribution of *Amyelois transitella* (Source: as in Appendix A)

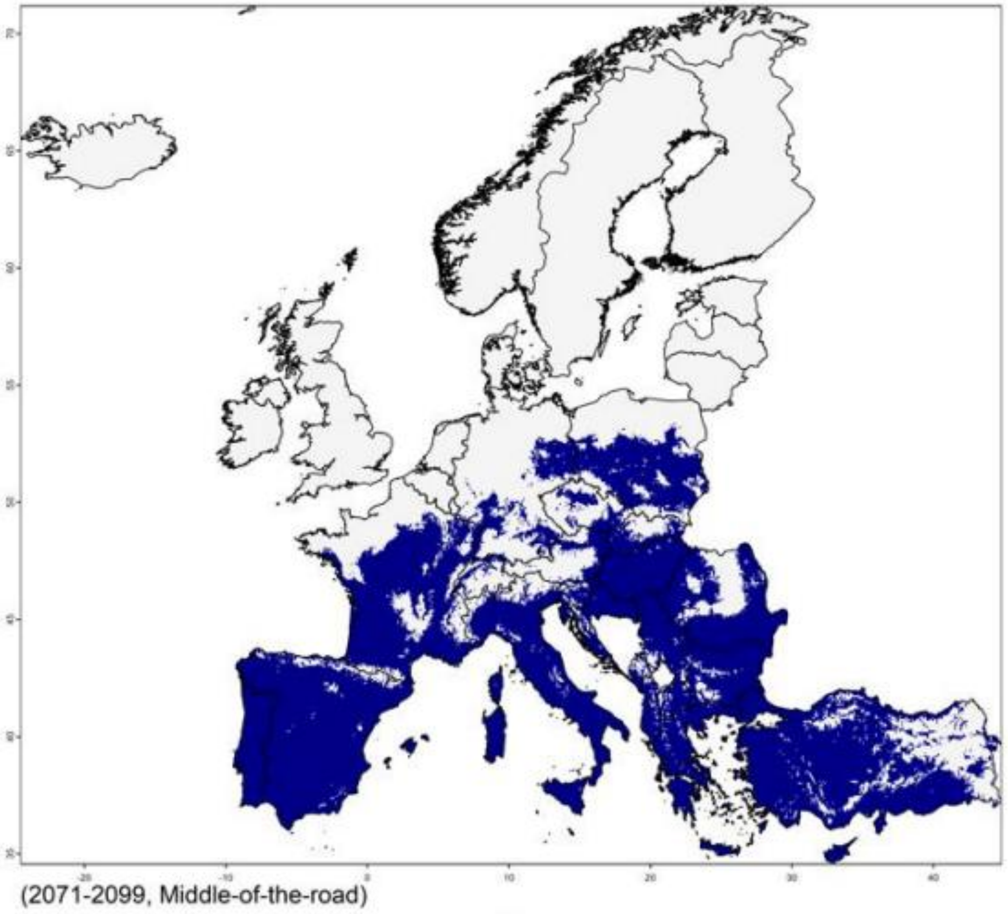
EFSA PLH Panel (EFSA Panel on Plant Health). 2021. Scientific Opinionon the pest categorisation of Amyelois transitella. EFSA Journal 2021;19(6):666

Effect of climate change on the agro-climatic zones suitable for *Amyelois transitella*

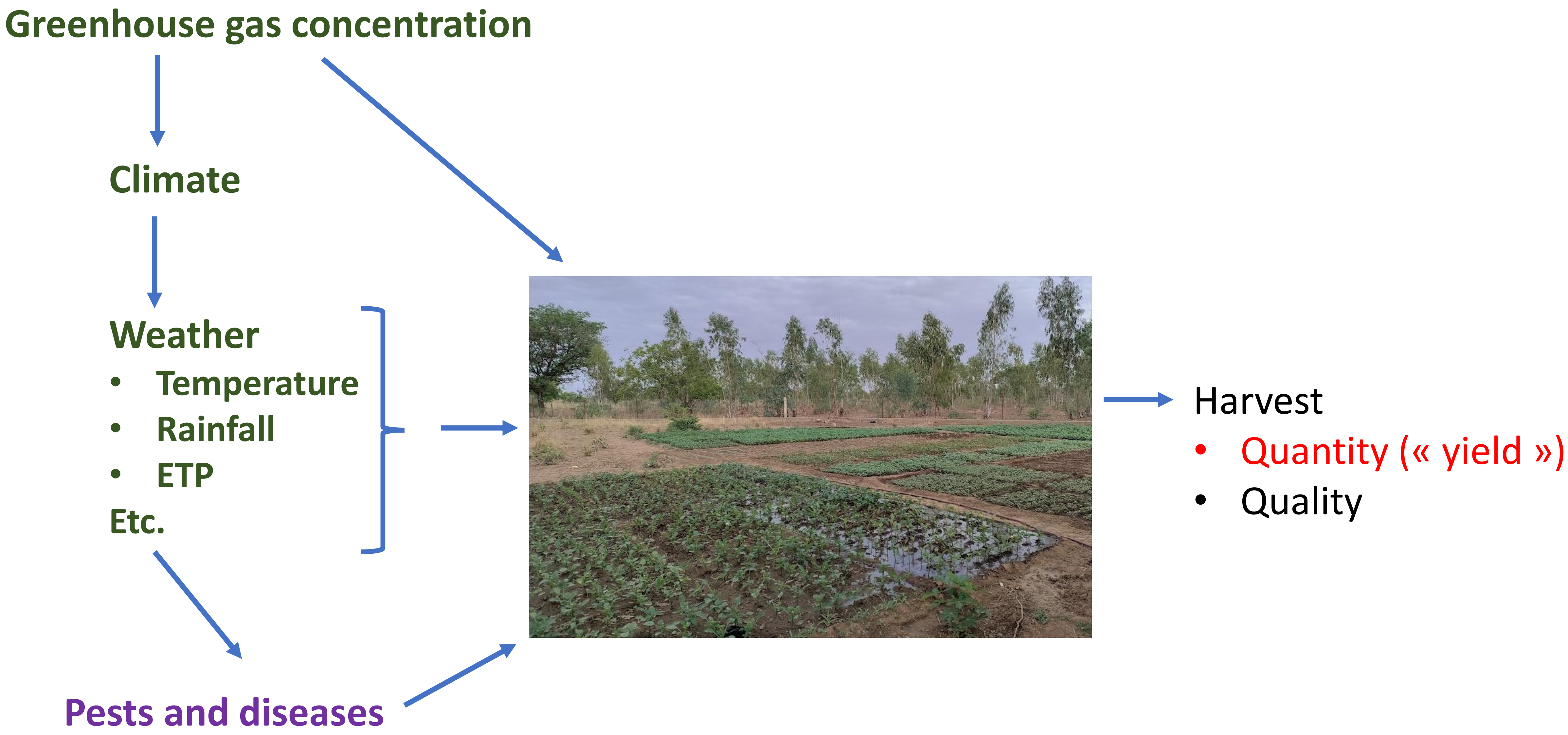
Current climate: 1991 -2020



Future climate: 2071-2099



DOI: 10.1127/entomologia/3551


Greenhouse gas concentration
Climate
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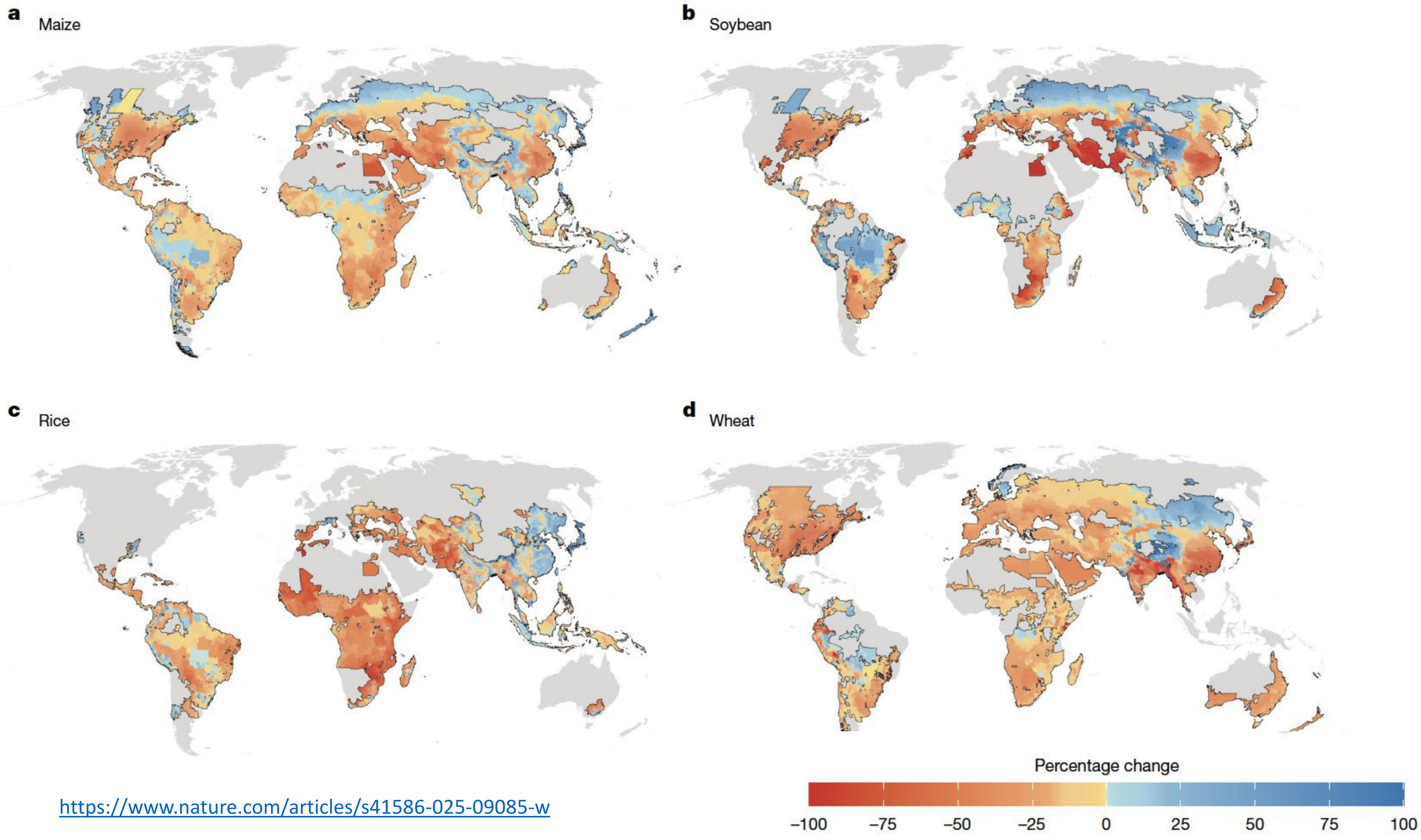
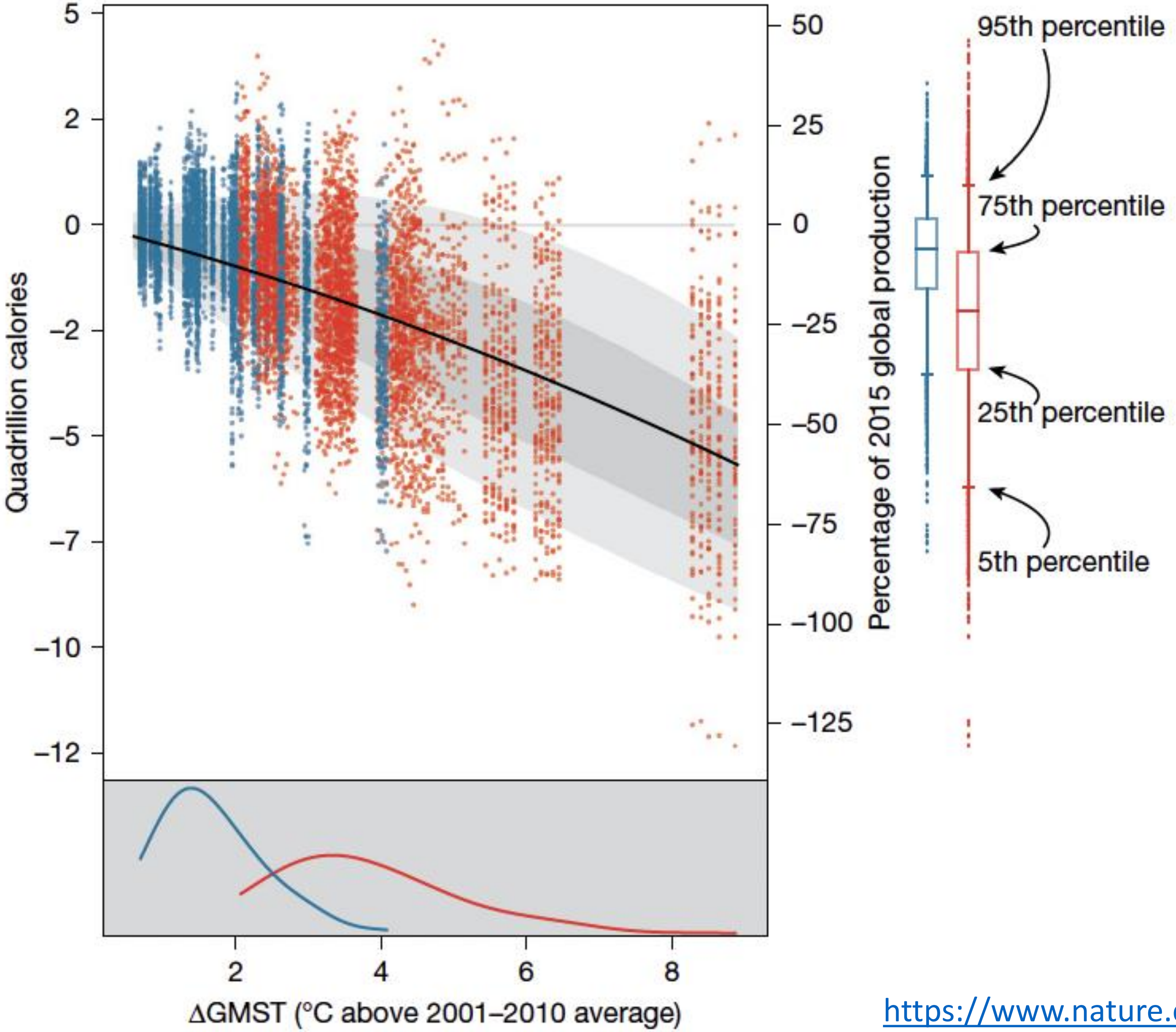
Rainfall
ETP
Etc.
Pests and diseases
Harvest
Quantity (« yield »)
Quality

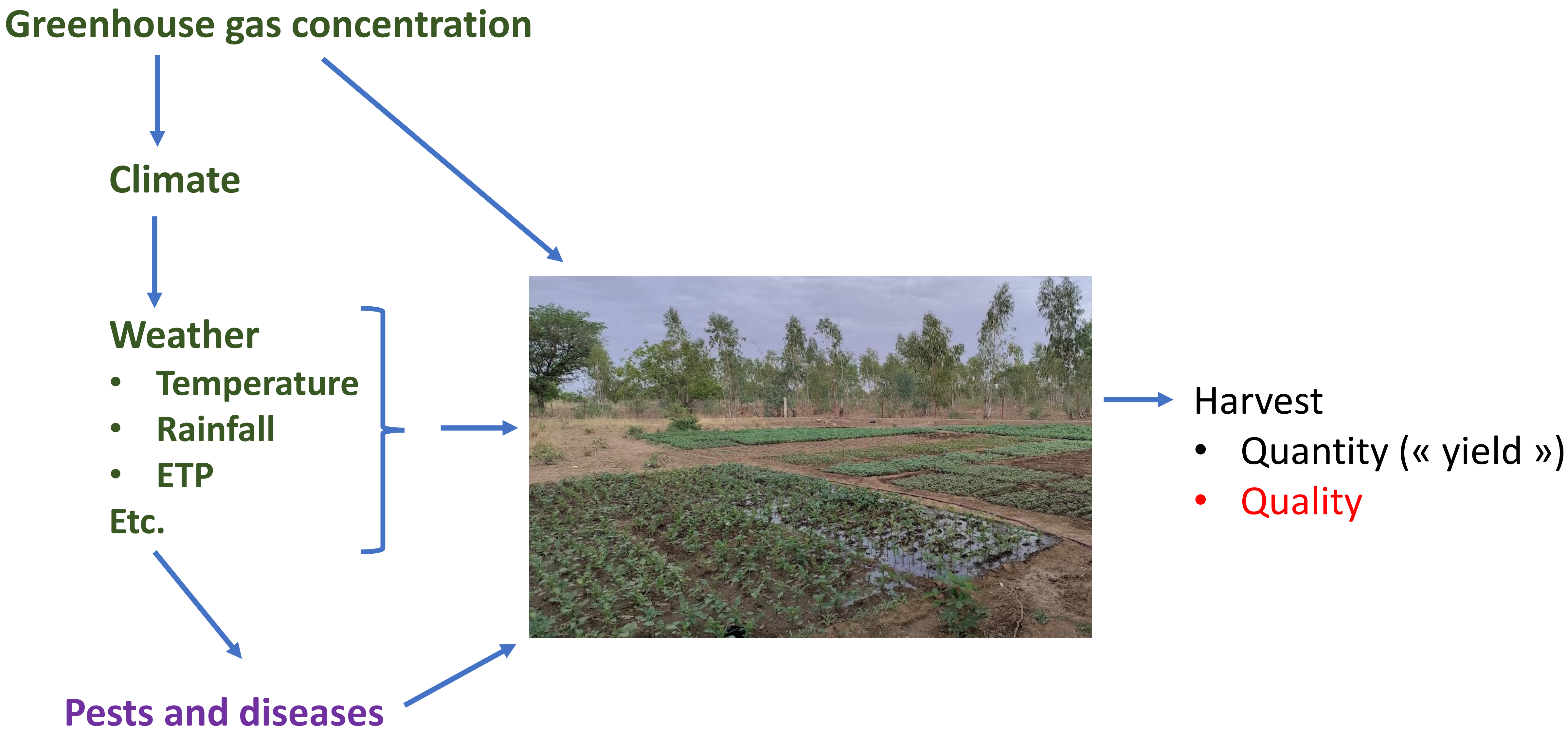
Estimated yield changes (%) under climate change scenarion RCP8.5 (2089-2098)



https://www.nature.com/articles/s41586-025-09085-w



https://www.nature.com/articles/s41586-025-09085-w



Greenhouse gas concentration
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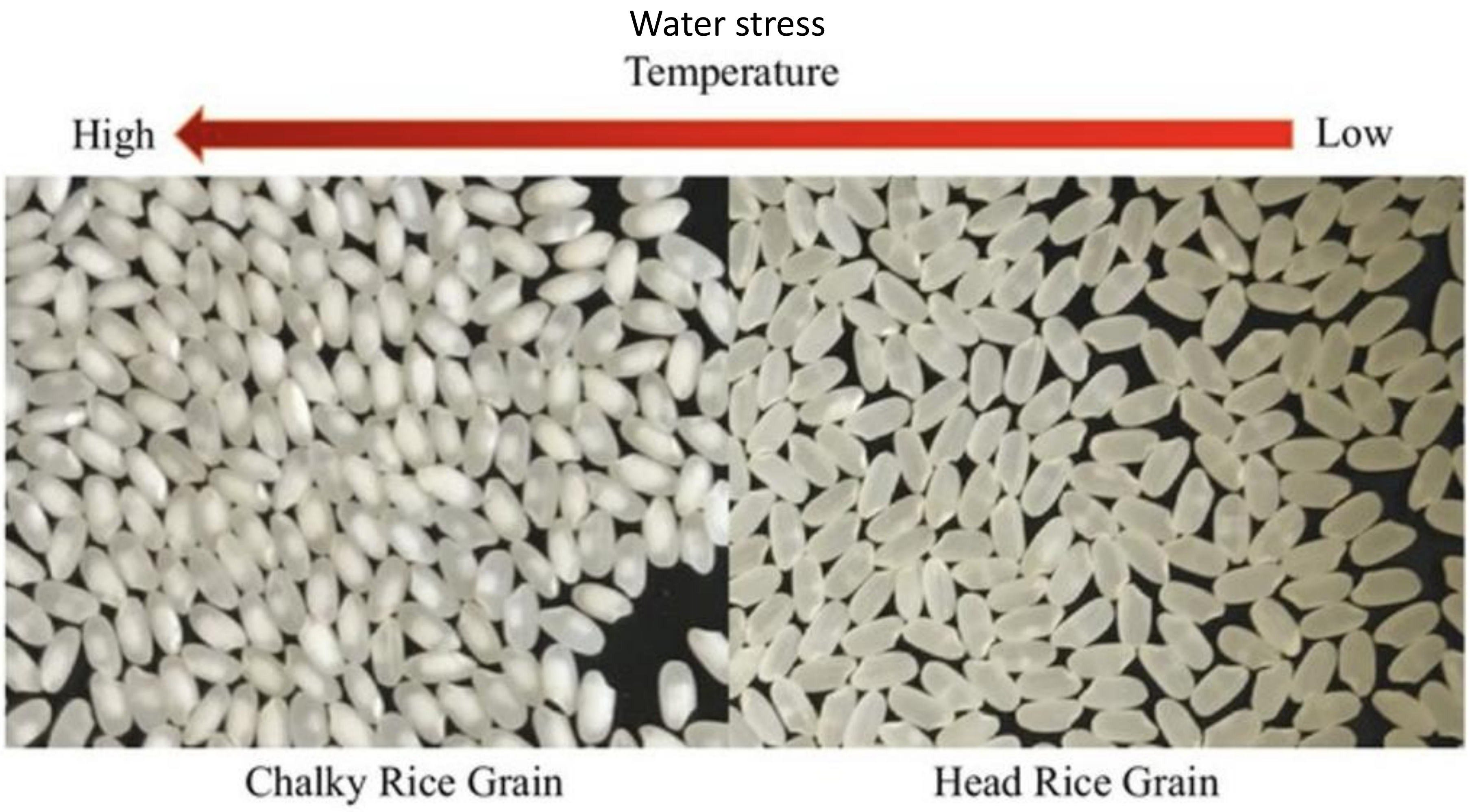
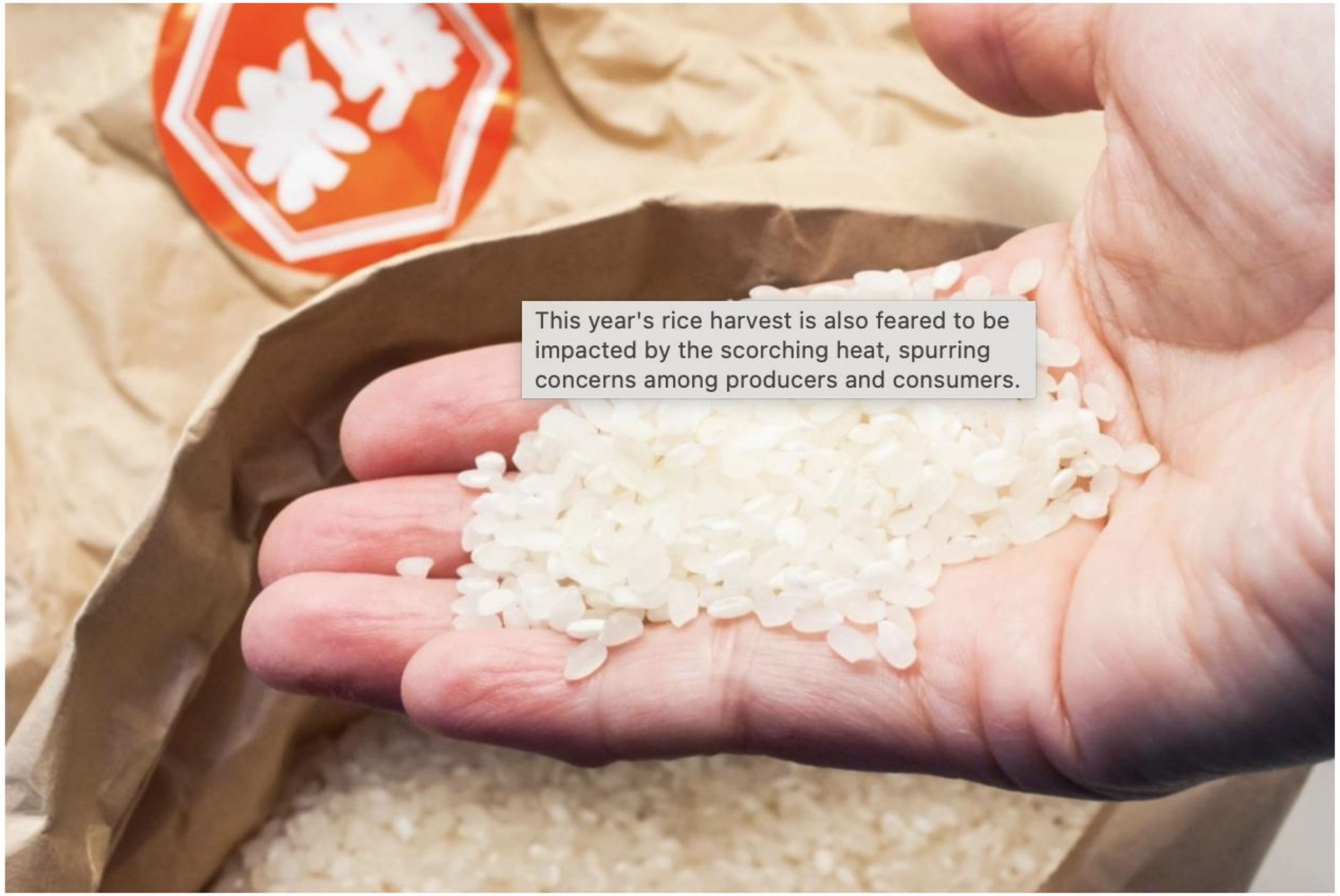
• Quality



Masutomi et al. 2022
DOI: 10.1007/s11027-022-10027-4

JAPAN

Heat waves impact Japan's rice quality, leading to shortage



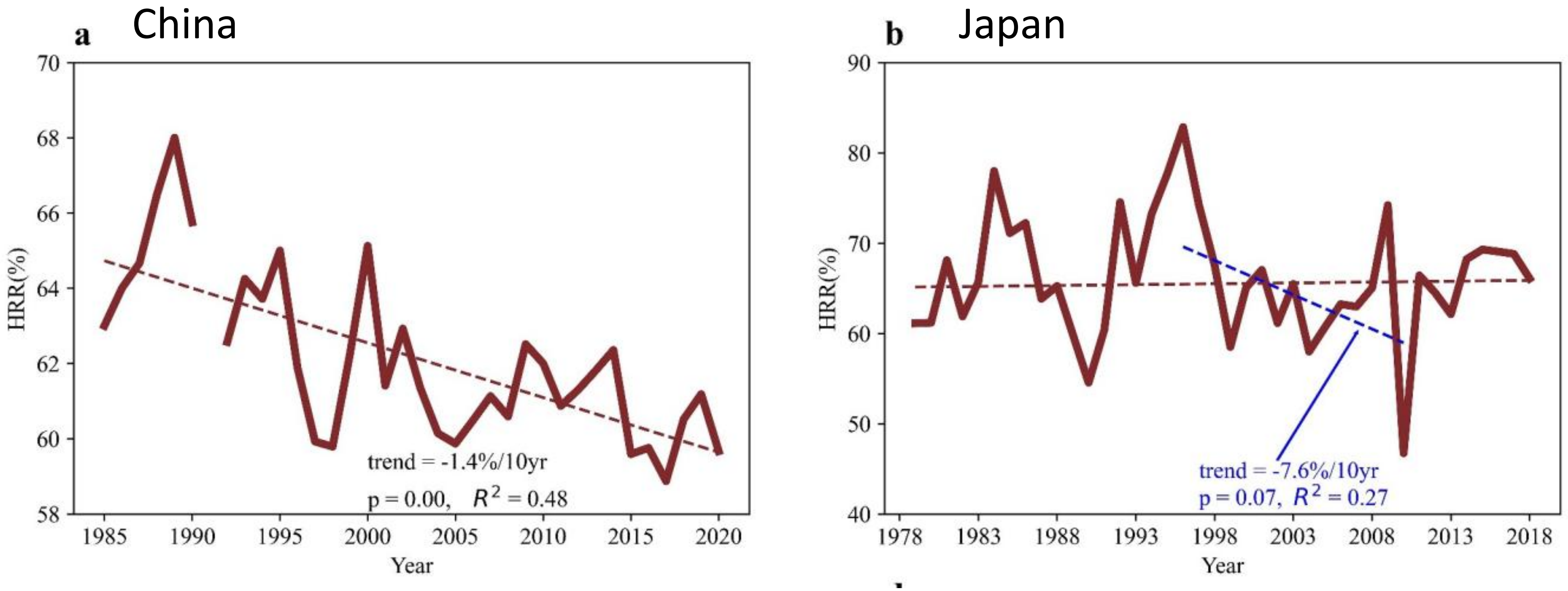
This year's rice harvest is also feared to be impacted by the scorching heat, spurring concerns among producers and consumers. | GETTY IMAGES

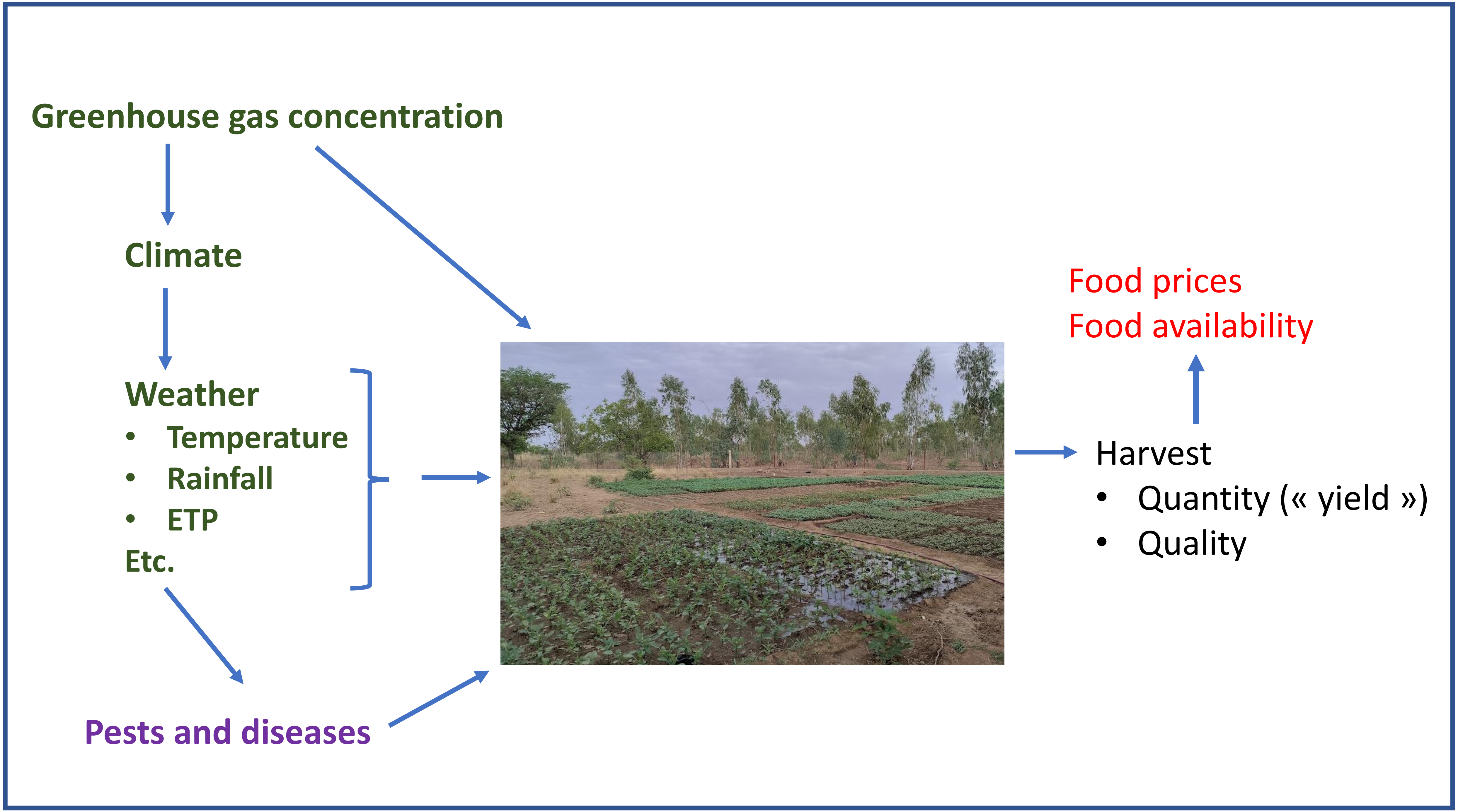
JIJI

SHARE/SAVE Jul 27, 2024

https://doi.org/10.1029/2024GL110557

Decrease of rice 1*st* quality grade in China and Japan

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Pests and diseases
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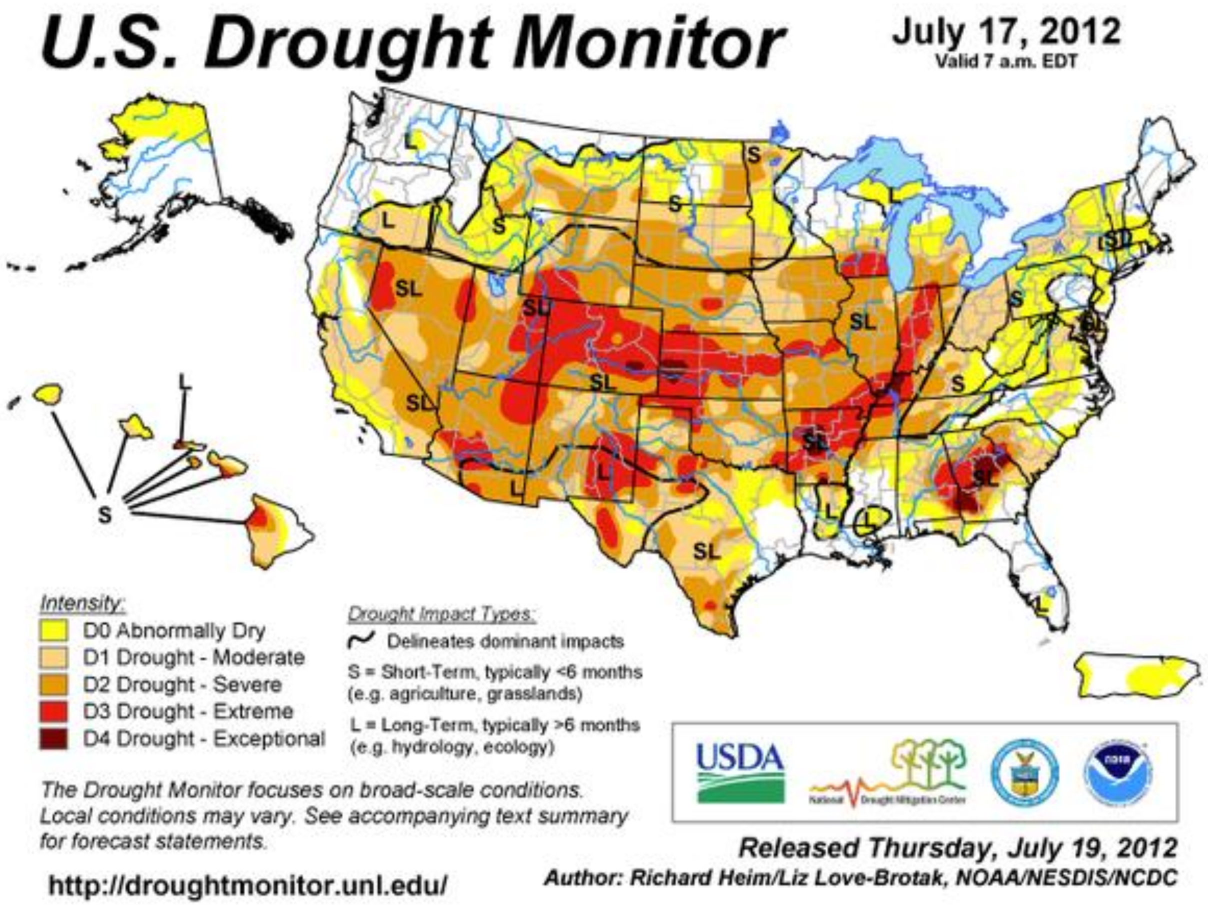
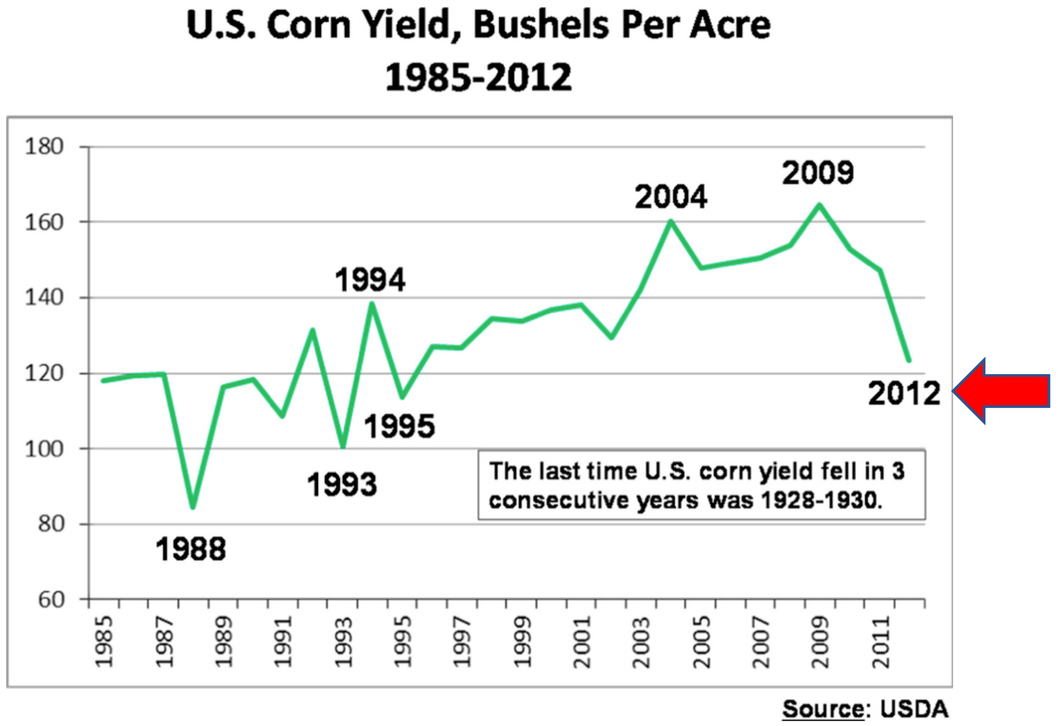
2012 US drought



The U.S. Drought Monitor map shows areas of the U.S. affected by drought as of July 17, 2012. Credit: NOAA/NESDIS/NCDC



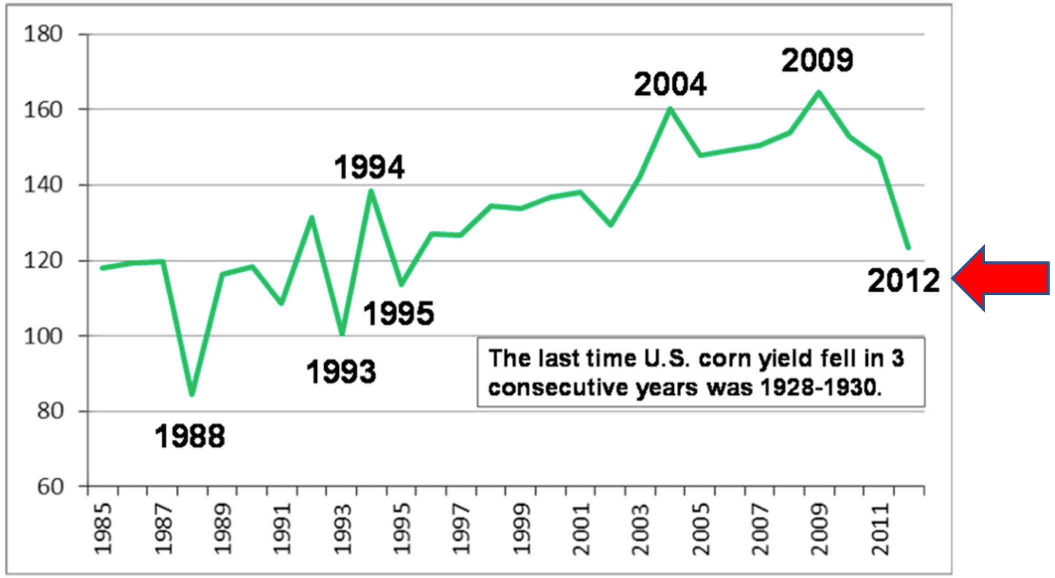
2012 US drought

JAMES WEST SCIENCE JUL 26, 2012 6:00 AM

Worst U.S. Drought in 50 Years to Raise Food Prices in 2013

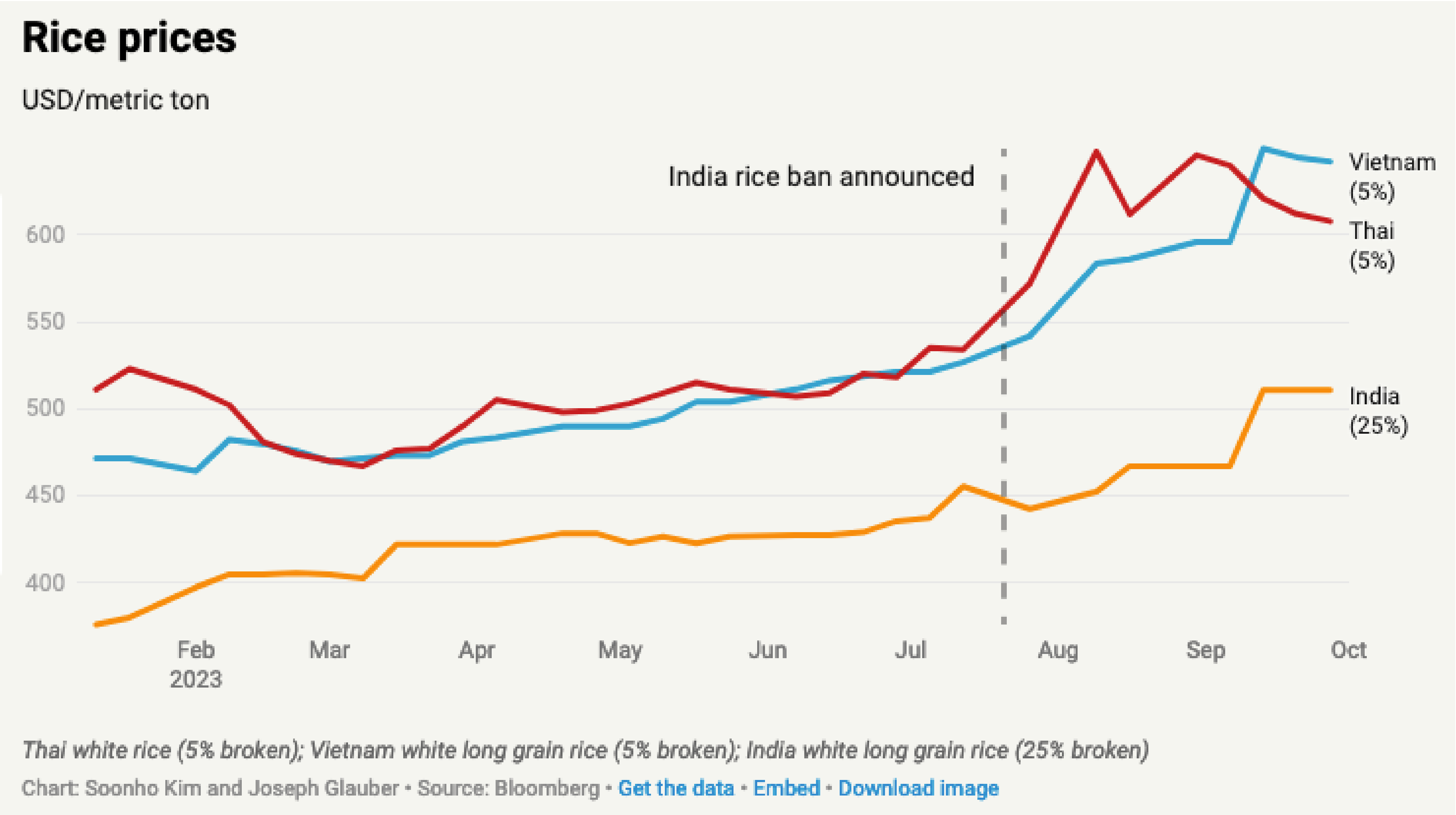
Image: James West/Climate Desk IMAGE: JAMES WEST/CLIMATE DESK

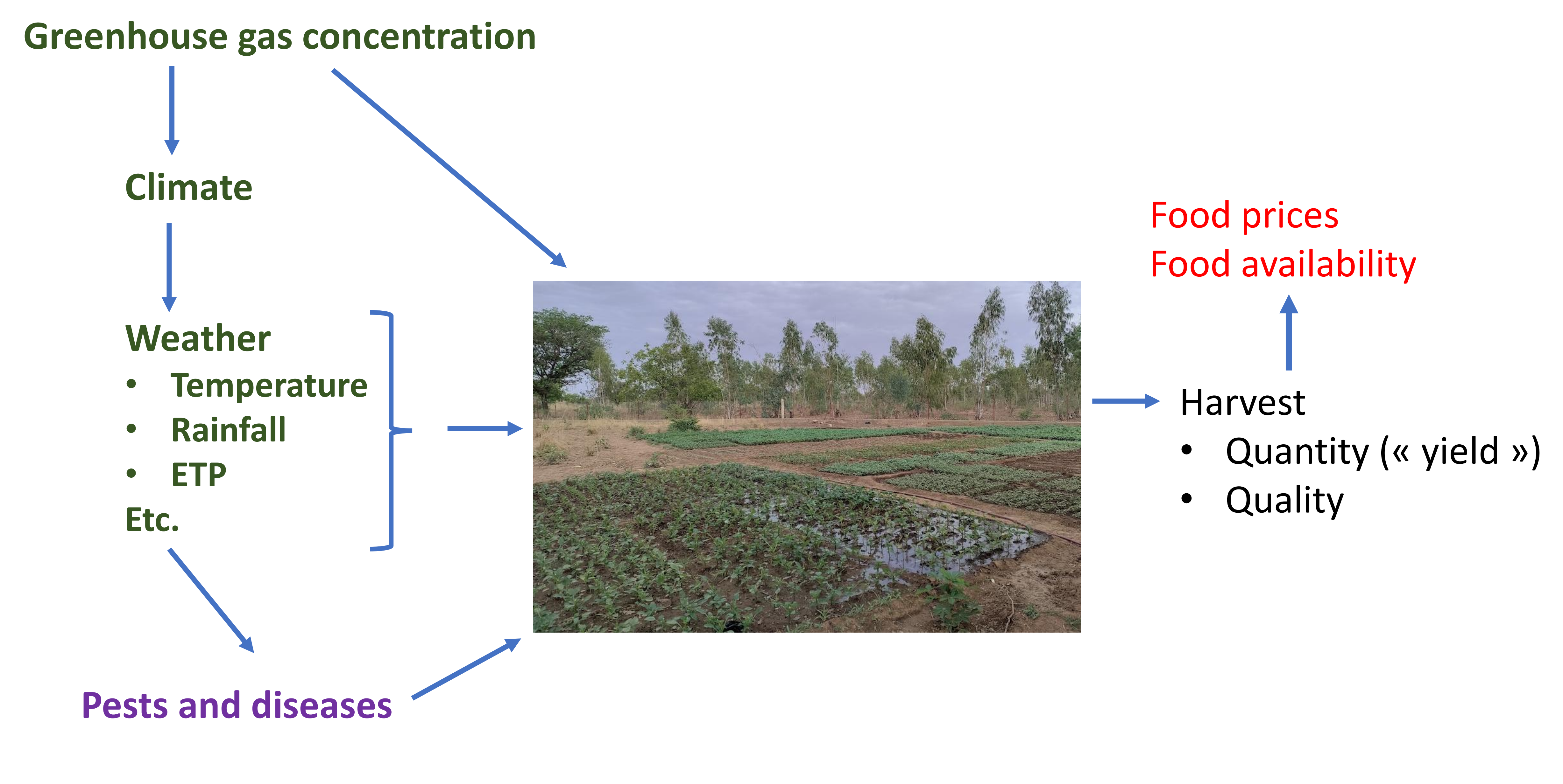
U.S. Corn Yield, Bushels Per Acre
1985-2012



Source: USDA

Strong increase of rice prices after the ban in 2023

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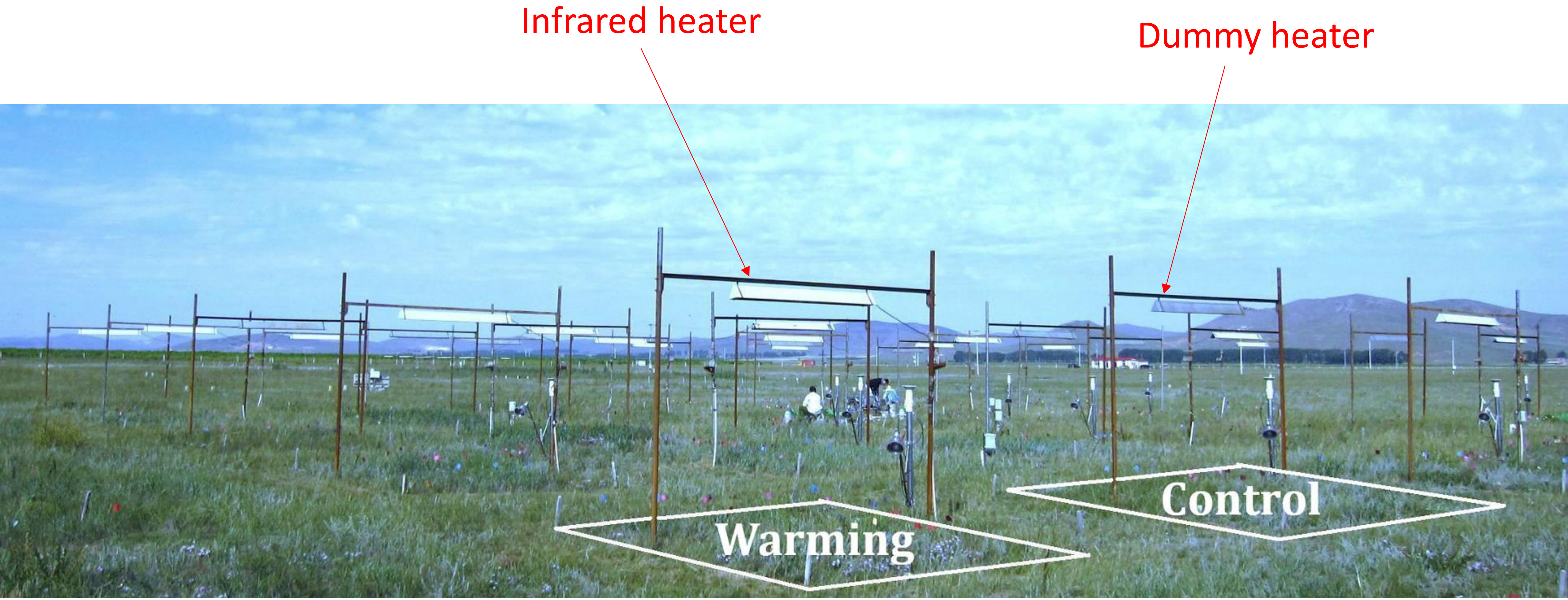
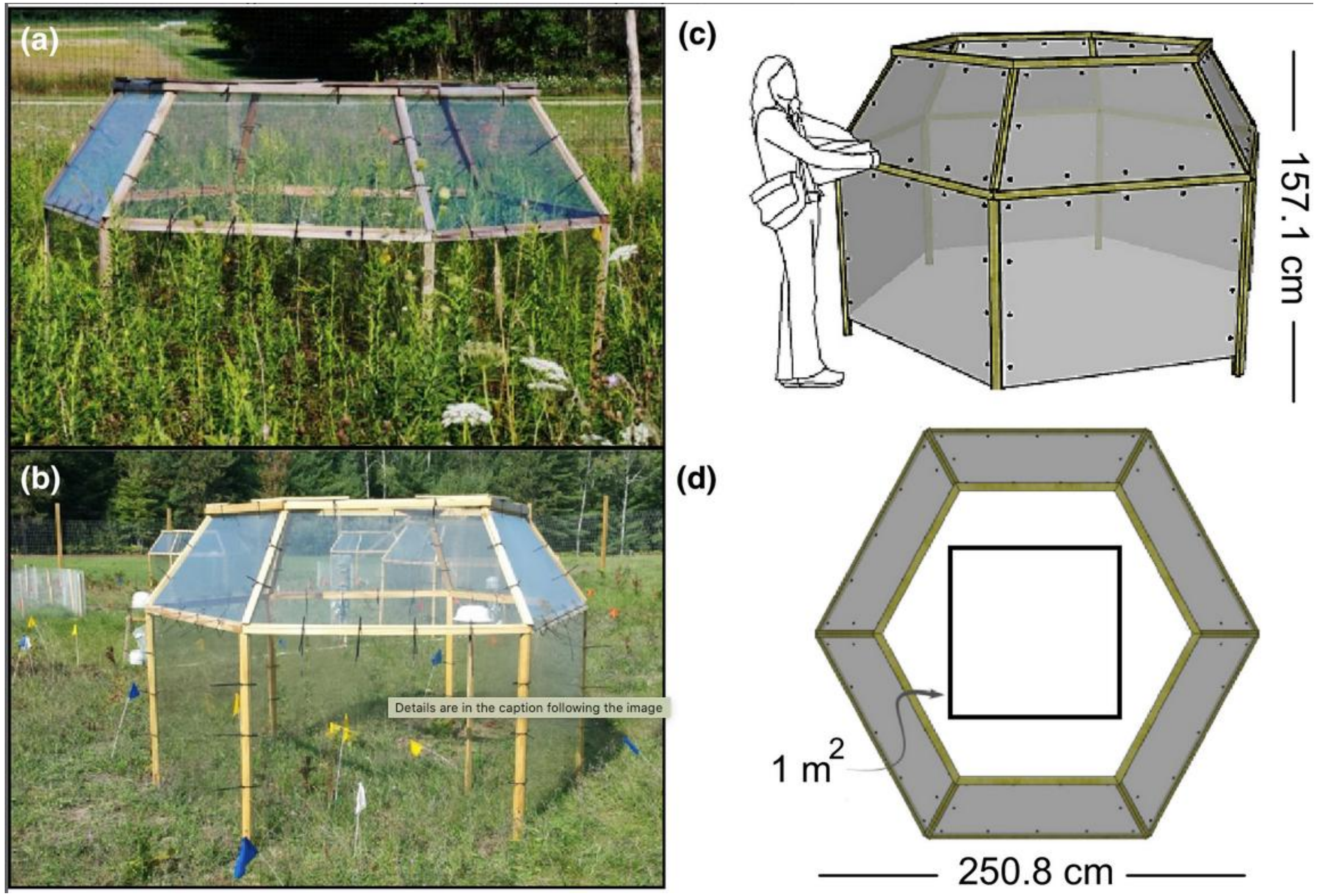
Field warming experiments



from Chi et al. 2013 doi.org/10.1371/journal.pone.0056482

Warming experiment: Open top chamber

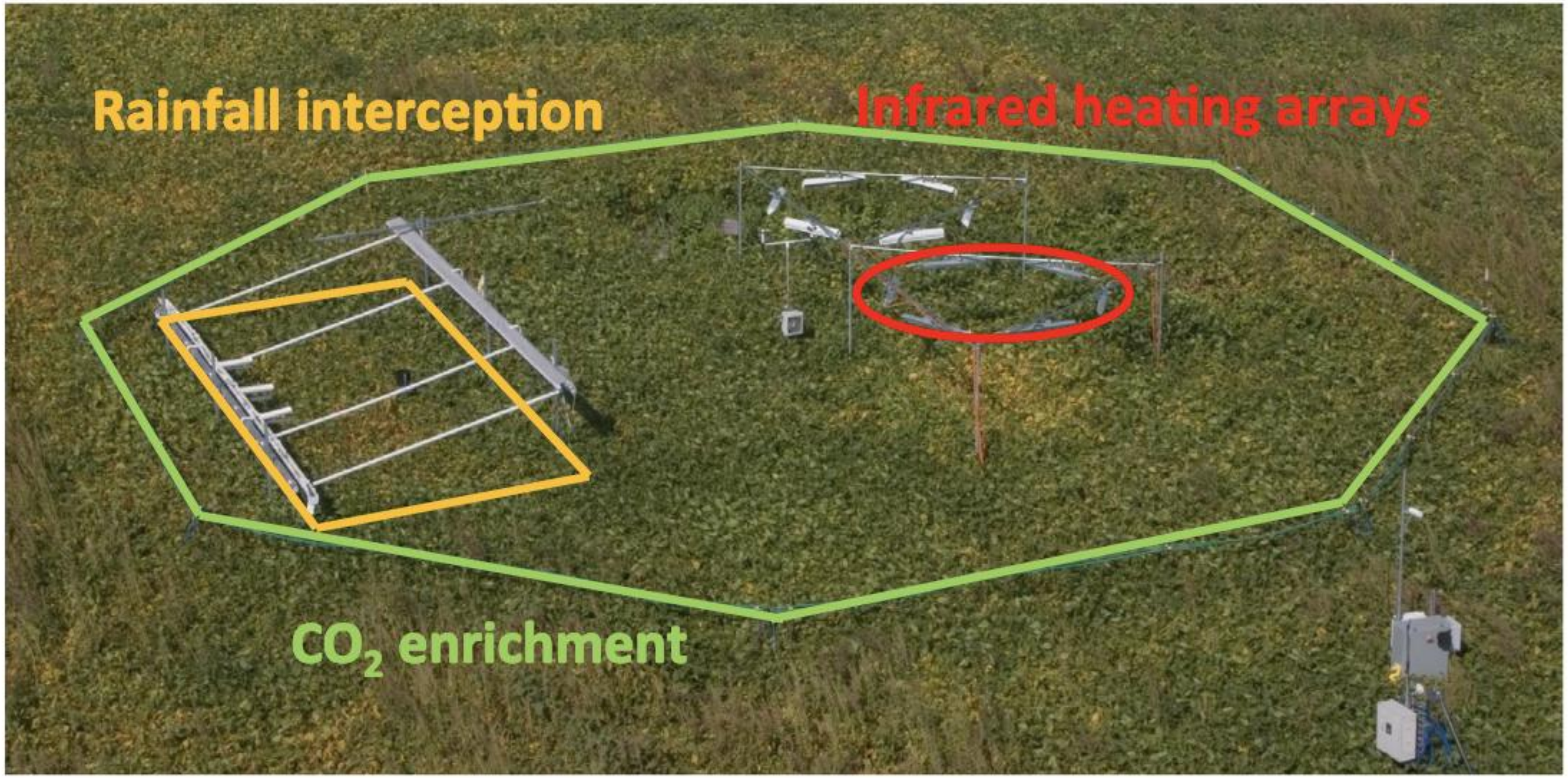


https://doi.org/10.1111/2041-210X.12863

Free-Air Carbon dioxide Enrichment (FACE)

- Experiment that raises the concentration of CO_2 in a specified area and allows the response of plant growth to be measured.

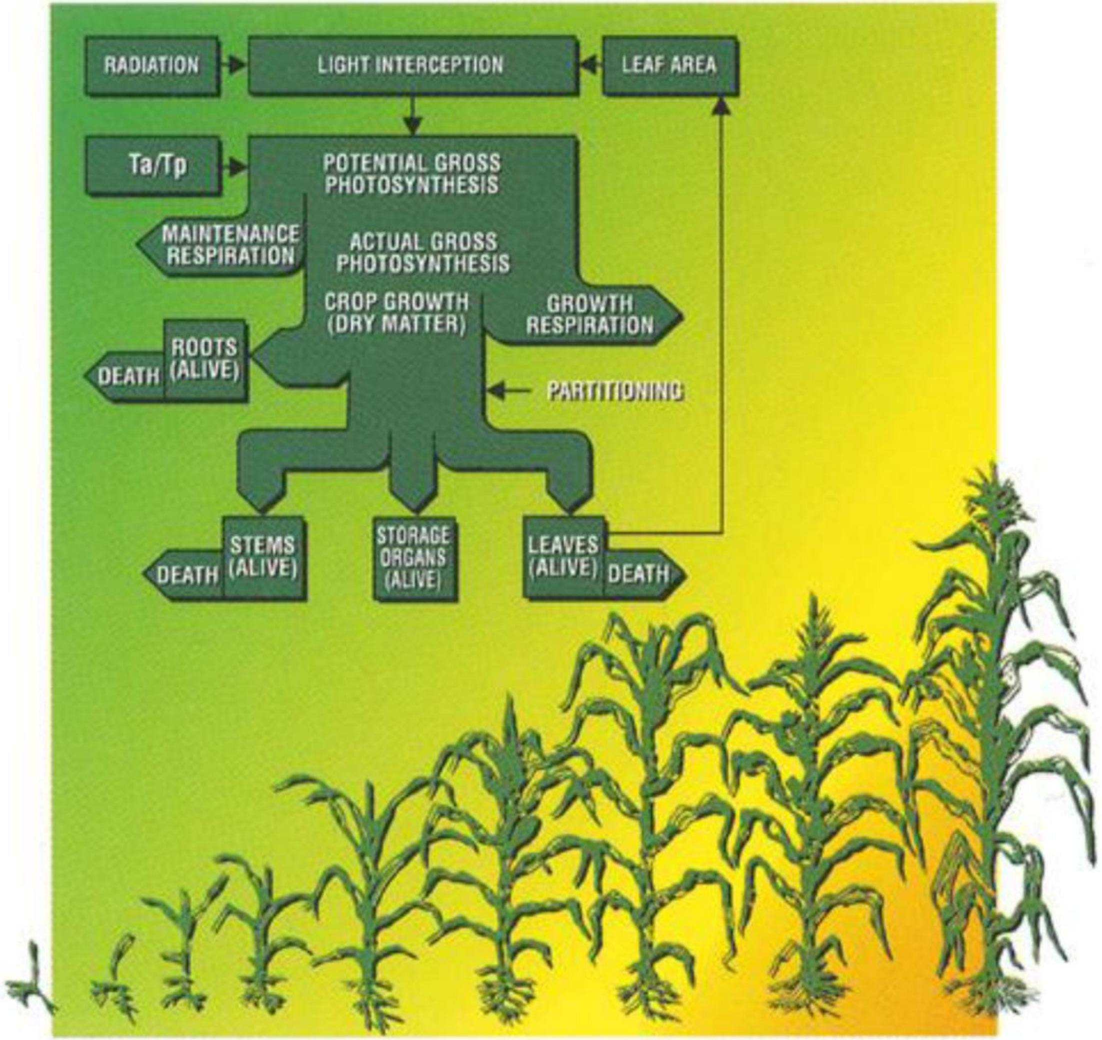
- Experiments using FACE are conducted in open areas.

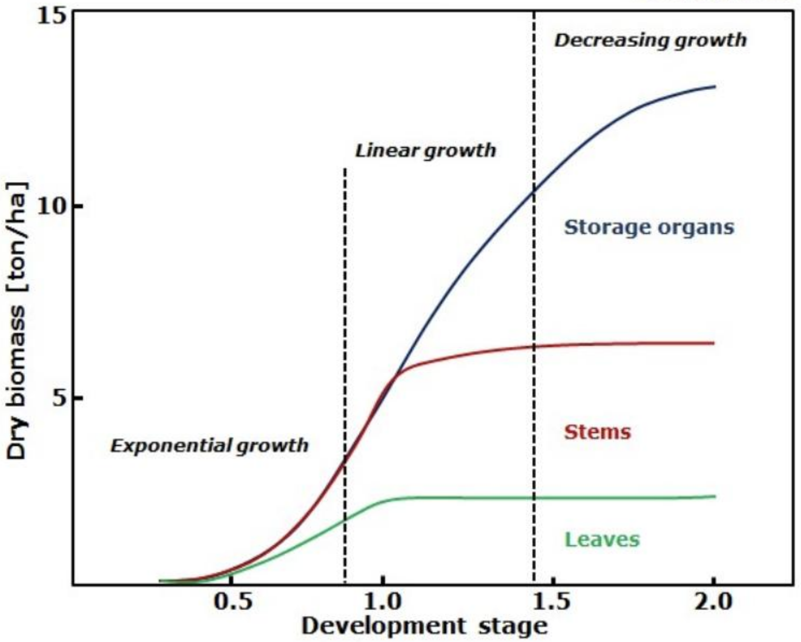


One of the 16 FACE rings at the Soybean free-air CO2 enrichment experiment showing nested drought and elevated temperature treatments. Drought was imposed using awnings to intercept rainfall during the growing season and pipe it away from the ring (Gray et al., 2016), and infrared heaters were used to heat the soybean canopy via feedback control (Ruiz-Vera et al., 2013).
Photograph courtesy of Dr. Andrew Leakey

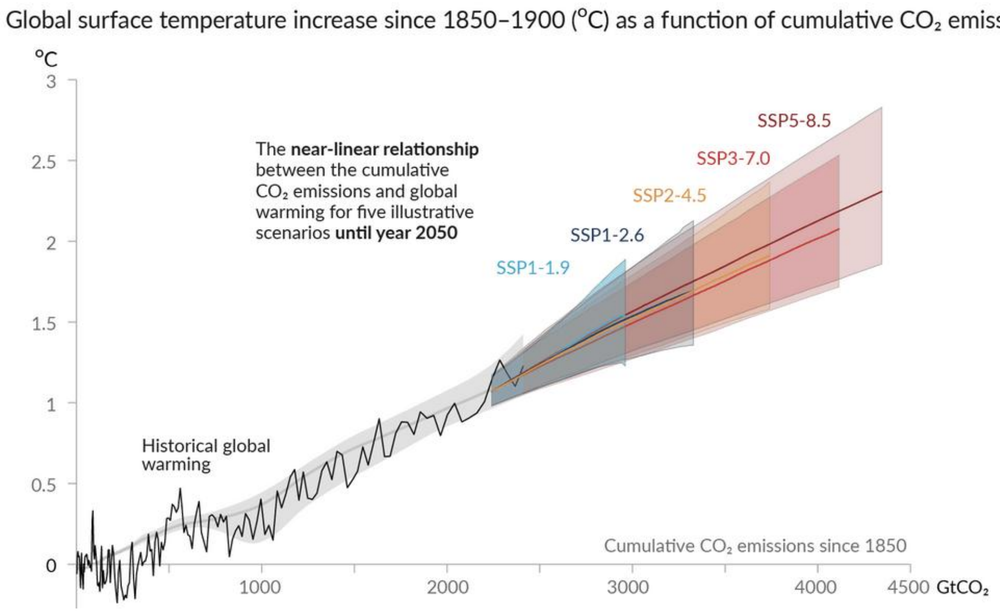
DOI: 10.1111/gcb.15375

WOFOST: process-based model used for crop yield forecast in Europe





Shared socio-economic pathway



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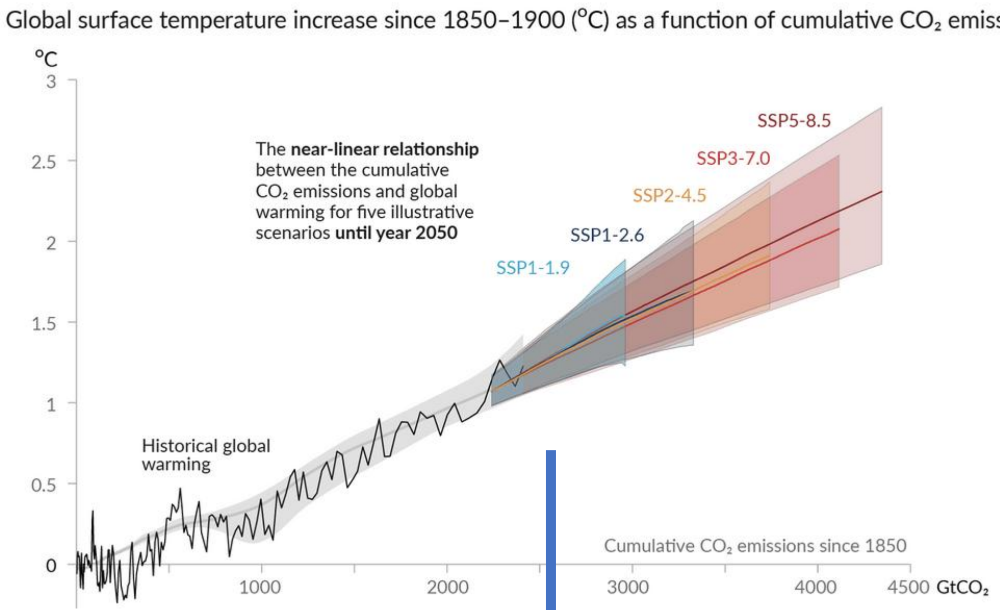
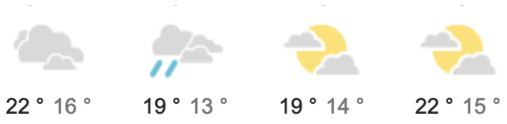


CO_2

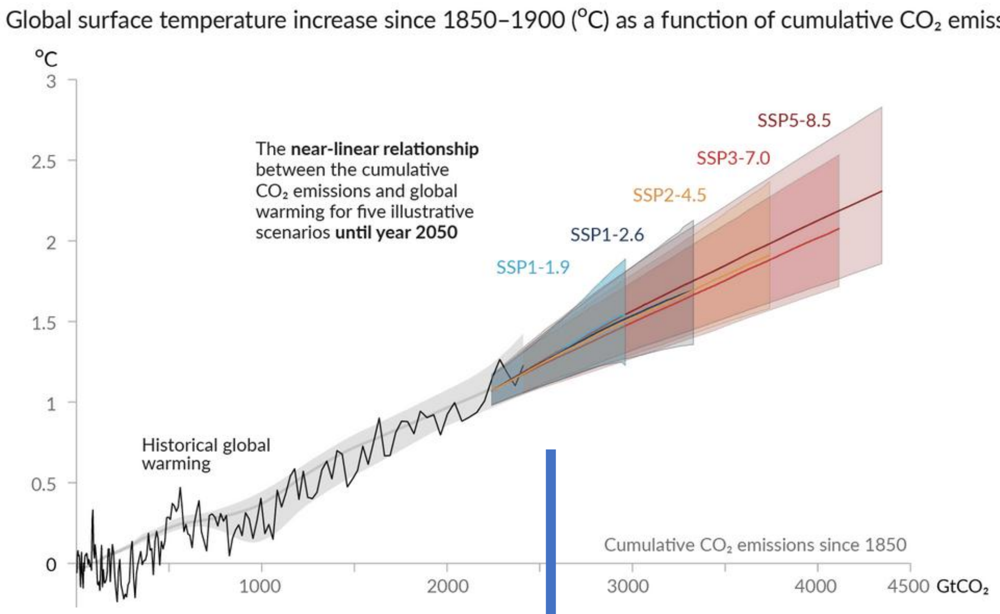


Climate conditions at specific locations

Weather inputs

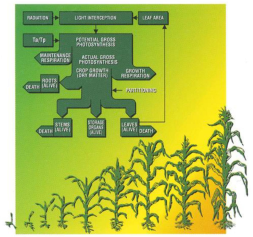
- Temperatures
- Radiations
- Rainfall etc.

Shared socio-economic pathway



Crop model

CO_2



Climate conditions at specific locations

Weather inputs

- Temperatures
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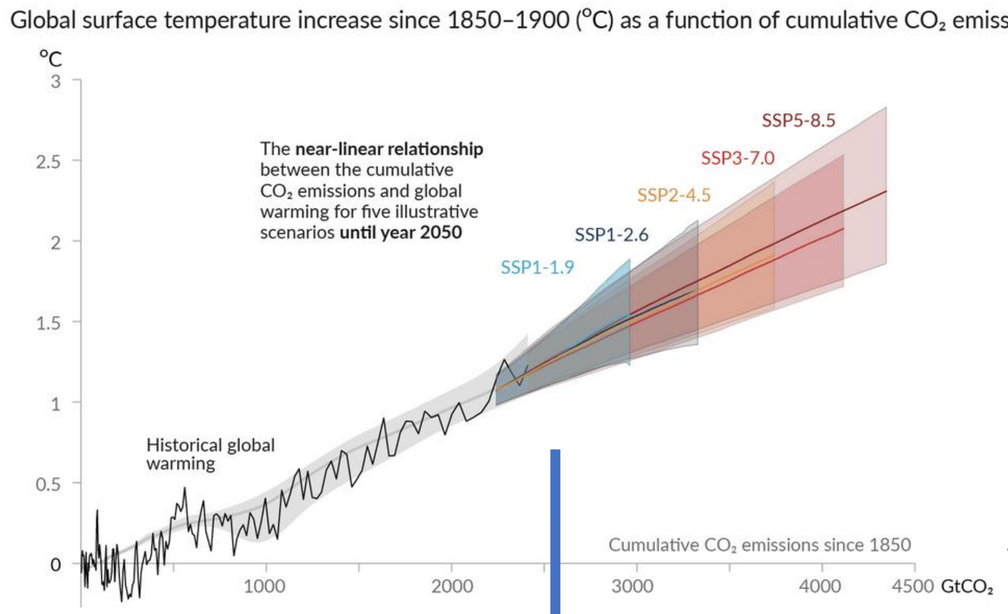
- Rainfall etc.

Other inputs

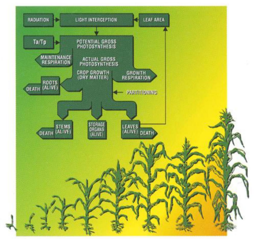
- Soil
- Farm practices
- Cultivar

Shared socio-economic pathway



CO_2

Crop model



- Crop yield
- Biomass
- Leaf area
- N content

Etc.

Climate conditions at specific locations

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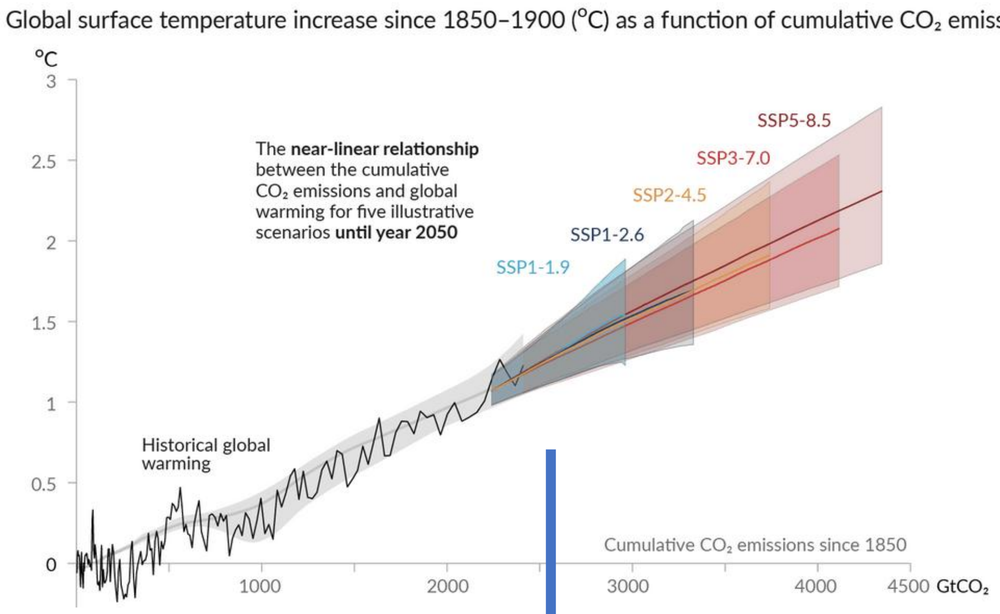
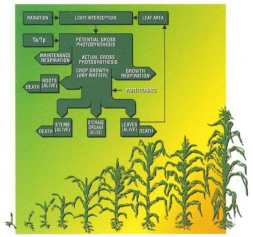
Shared socio-economic pathway



Climate conditions at specific locations

CO_2

Crop model



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Etc.

Weather inputs

- Temperatures
- Radiations
- Rainfall etc.

Other inputs

- Soil
- **Farm practices**
- **Cultivar**

Outline

- Why climate change is important for food security?
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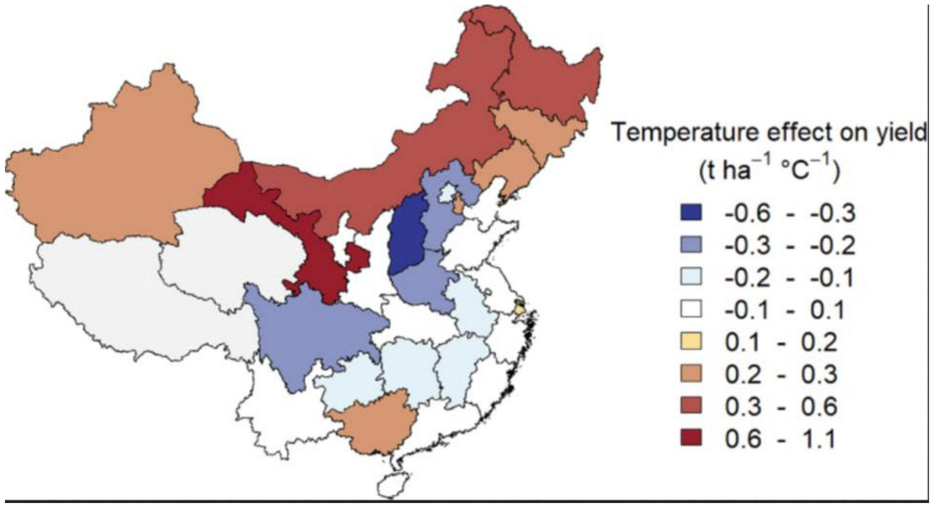
How to adapt cropping systems to climate change?

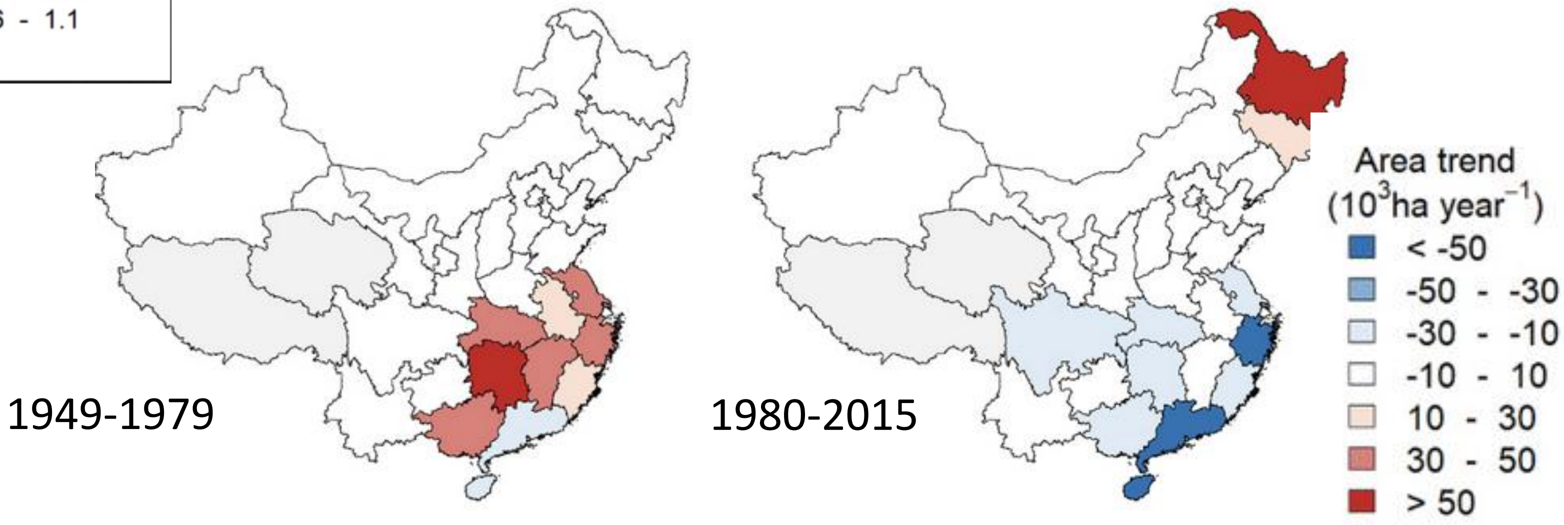
How to adapt cropping systems to climate change?

1. **Crop migration/Crop substitution**

Northward migration of rice cropping area in China due to climate change

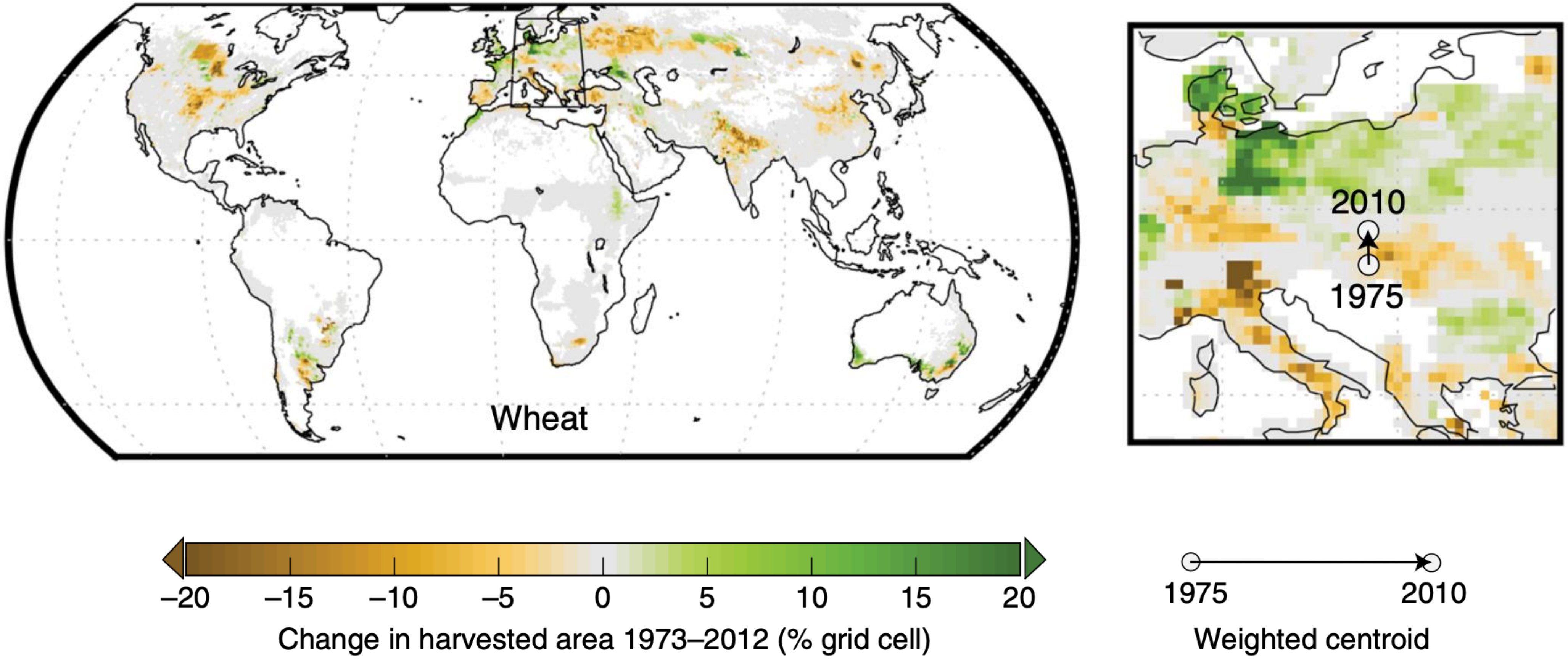


Rice



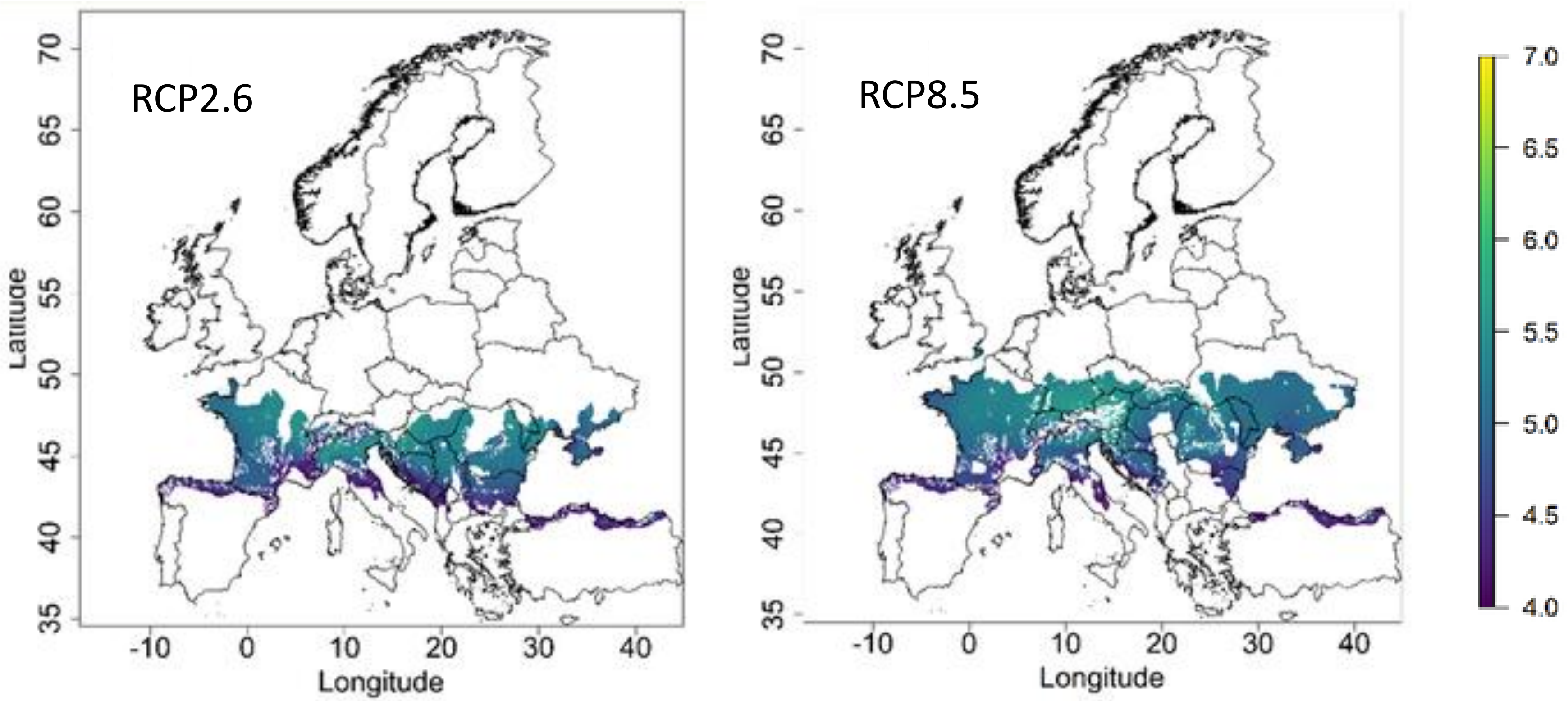
https://iopscience.iop.org/article/10.1088/2515-7620/ab0856

Northward migration of wheat cropping area in Europe due to climate change



https://doi.org/10.1038/s41467-020-15076-4

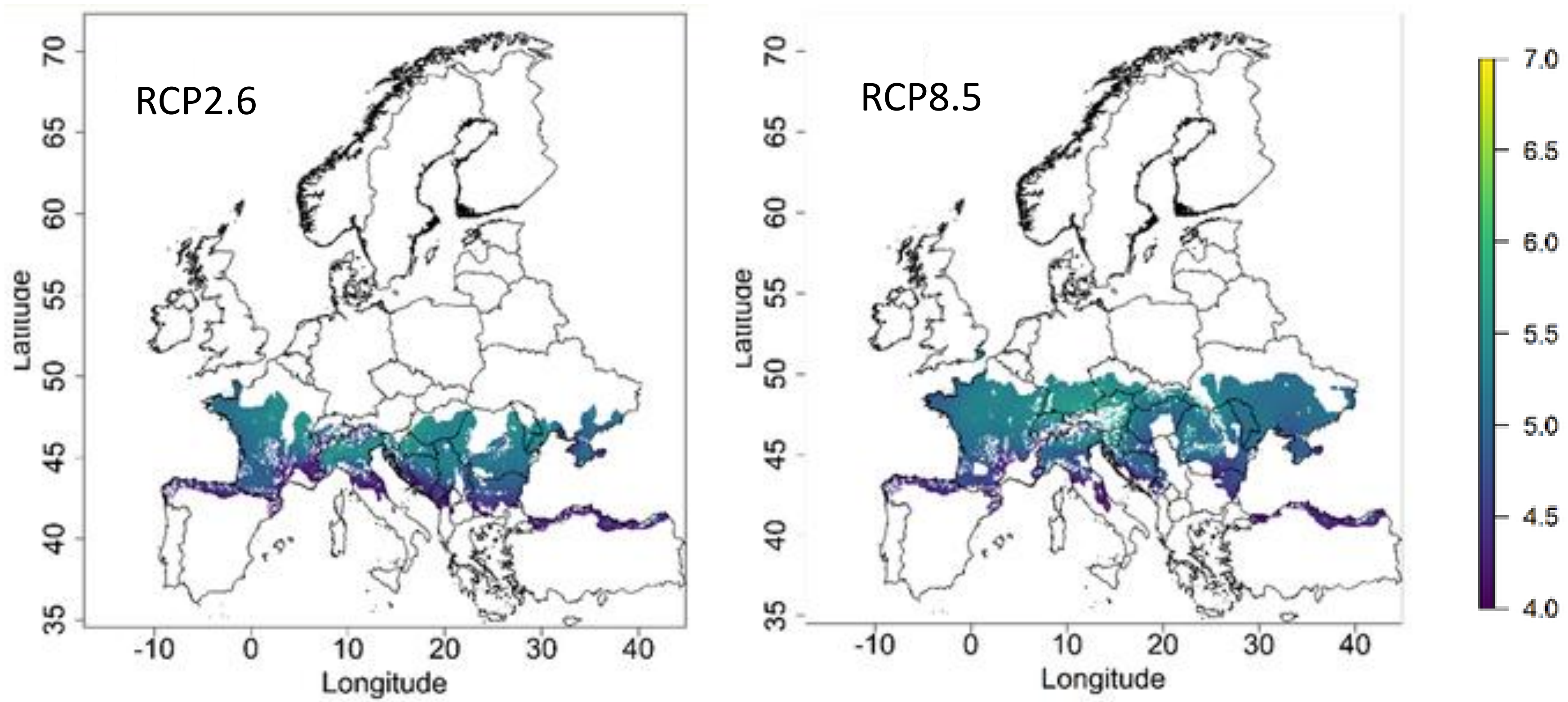
Sorghum at the end of the century



Cropland area with high and consistent sorghum yield (average > 4 t ha^{-1} and yield standard variation < 0.5 t ha^{-1}).

https://meetingorganizer.copernicus.org/EGU24/EGU24-1367.html

Sorghum at the end of the century



Cropland area with high and consistent sorghum yield (average > 4 t ha^{-1} and yield standard variation < 0.5 t ha^{-1}).

At least 90% of maize currently used to feed livestock could be replaced by sorghum in Europe if sorghum was grown in one out of year in three years

https://meetingorganizer.copernicus.org/EGU24/EGU24-1367.html

How to adapt cropping systems to climate change?

1. Crop migration/Crop substitution
2. **Plant breeding/New cultivars**

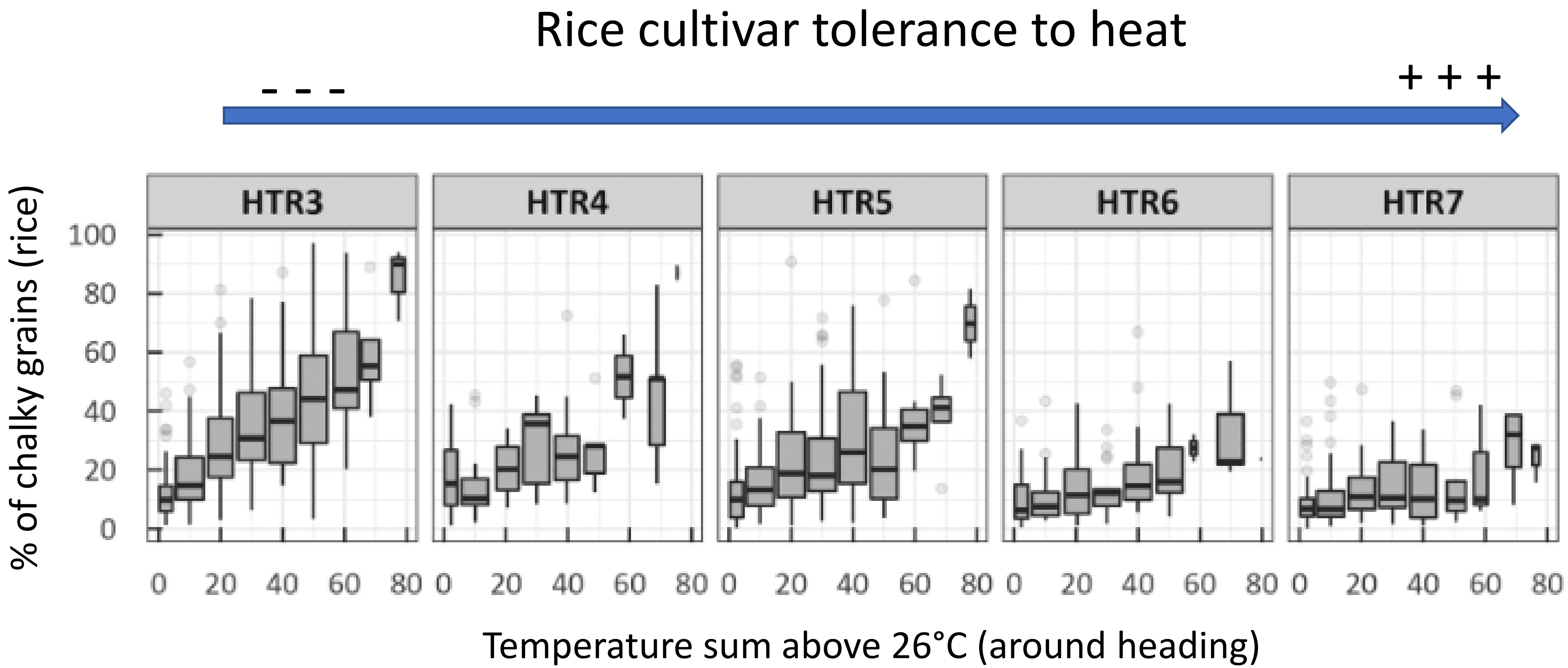


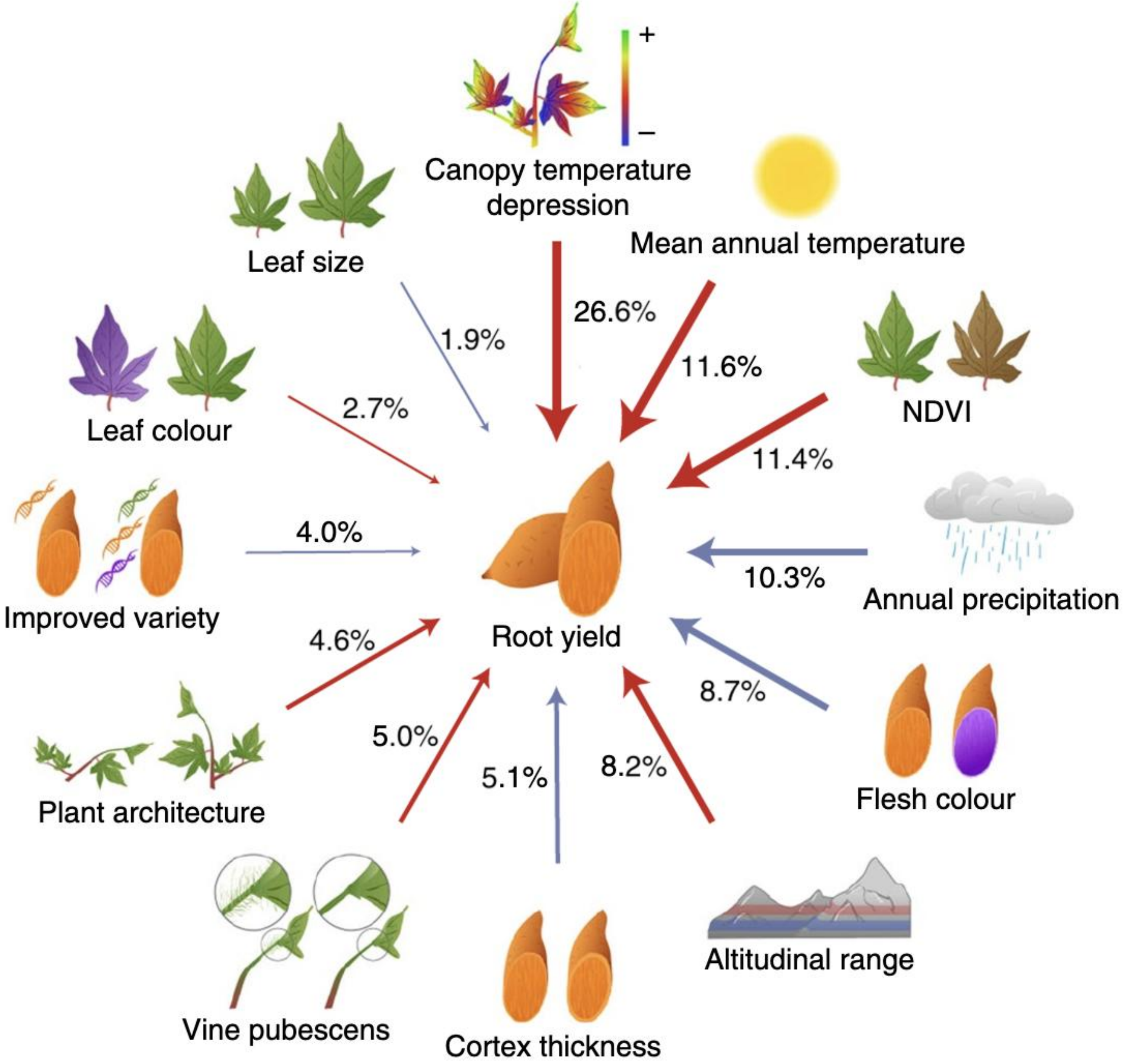
Fig. 2. Boxplot of measured chalky grain (CG, %) in relationship to TaHD (°C d, representing the sum of temperature above 26°C, 20 days after heading) for each HTR category. Each box indicates the interquartile range (IQR) and the middle line in the box represents the median. The upper- and lower-end of whiskers are median 1.5 × IQR ± median. Open circles are values outside the 1.5 × IQR.

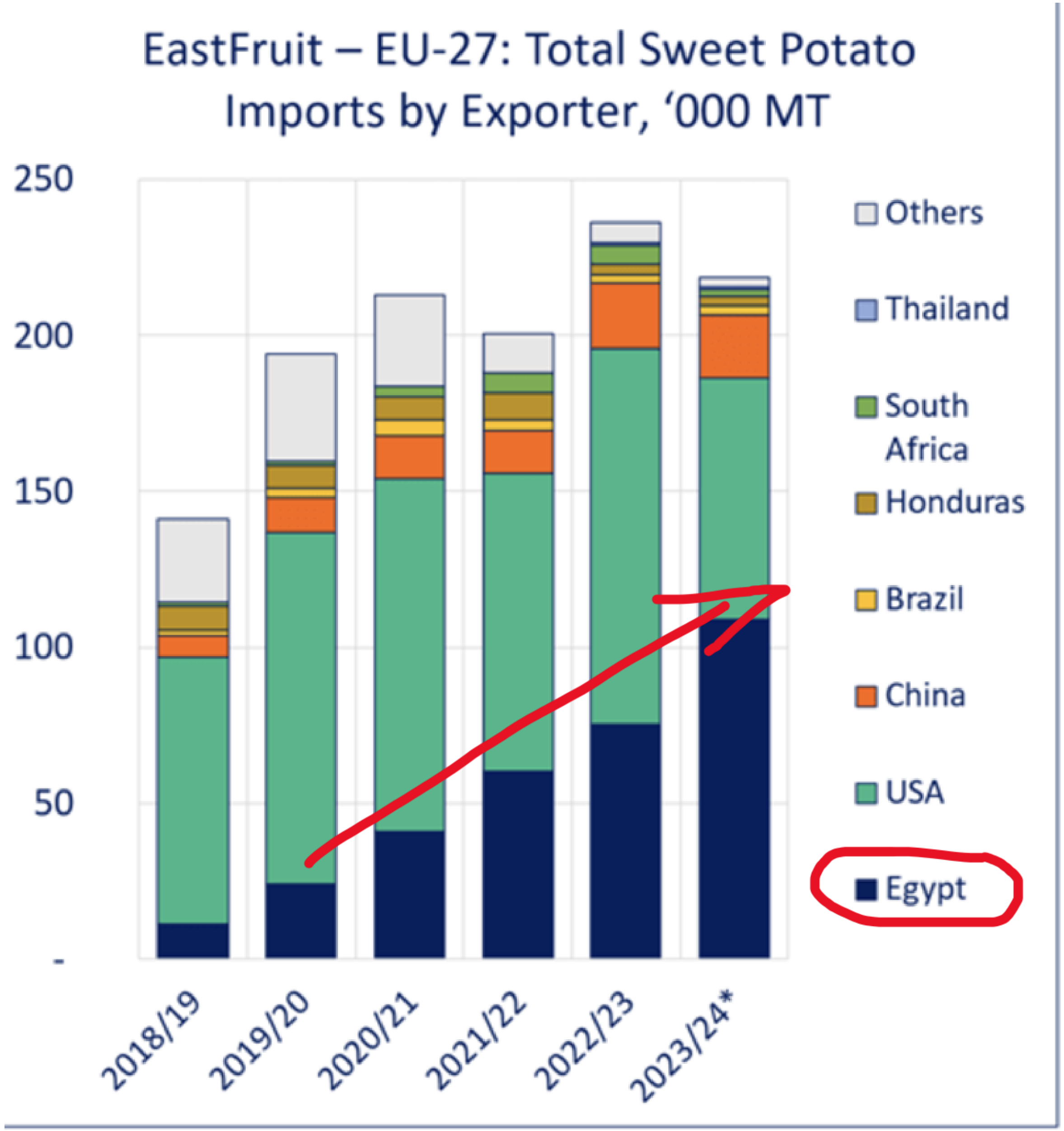
https://doi.org/10.1016/j.fcr.2024.109303

ARTICLES
https://doi.org/10.1038/s41558-020-00924-4
nature climate change

Intraspecific diversity as a reservoir for heat-stress tolerance in sweet potato

Bettina Heider[1]✉, Quentin Struelens[2,3], Émile Faye[4], Carlos Flores[1], José E. Palacios[5], Raul Eyzaguirre[1], Stef de Haan[1] and Olivier Dangles[2]✉





Data from Global Trade Tracker. Analysis by EastFruit

How to adapt cropping systems to climate change?

1. Crop migration/Crop substitution
2. Plant breeding/New cultivars
3. **Sowing & harvest dates**

nature communications

Article

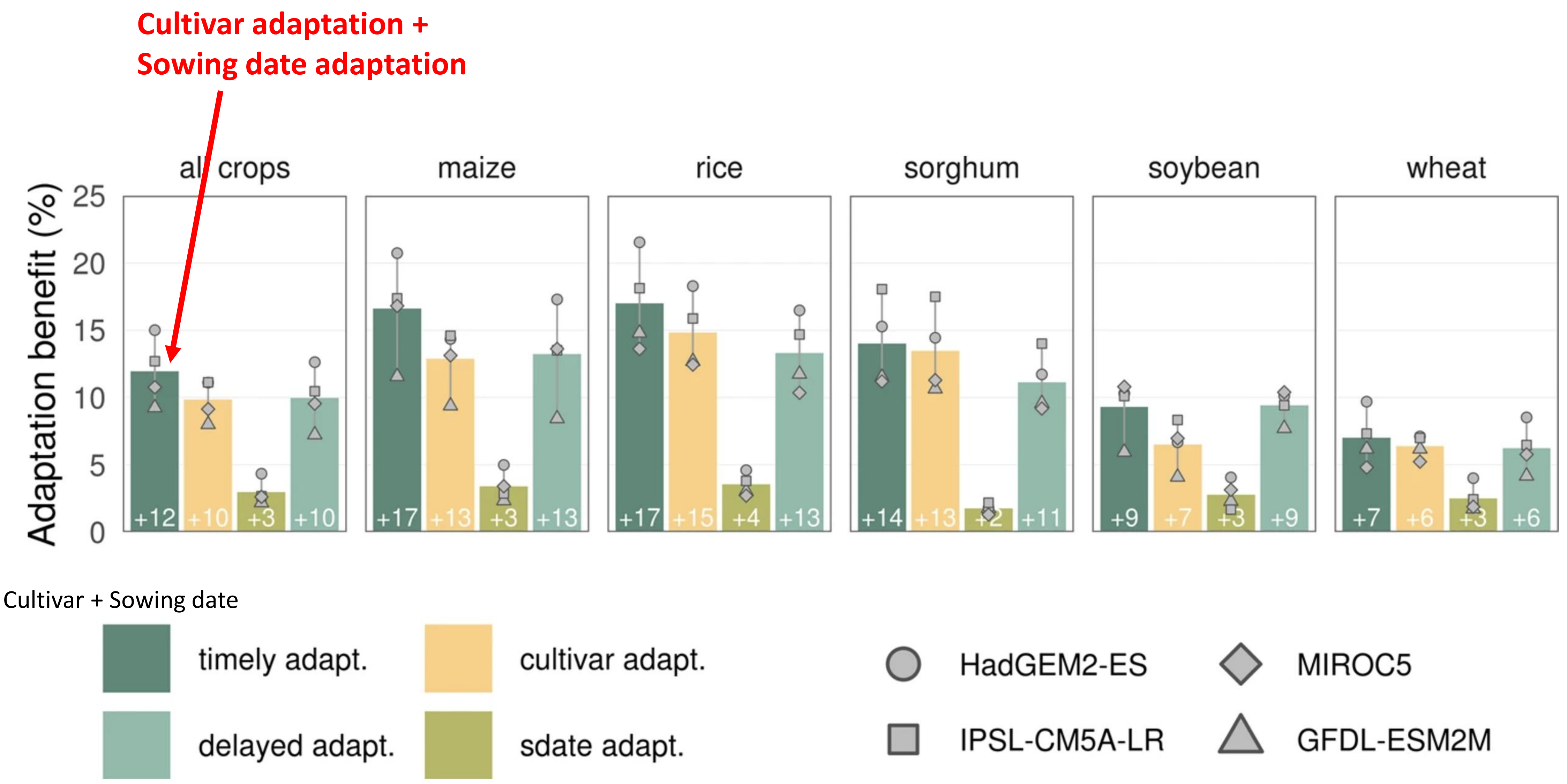
https://doi.org/10.1038/s41467-022-34411-5

Global crop yields can be lifted by timely adaptation of growing periods to climate change

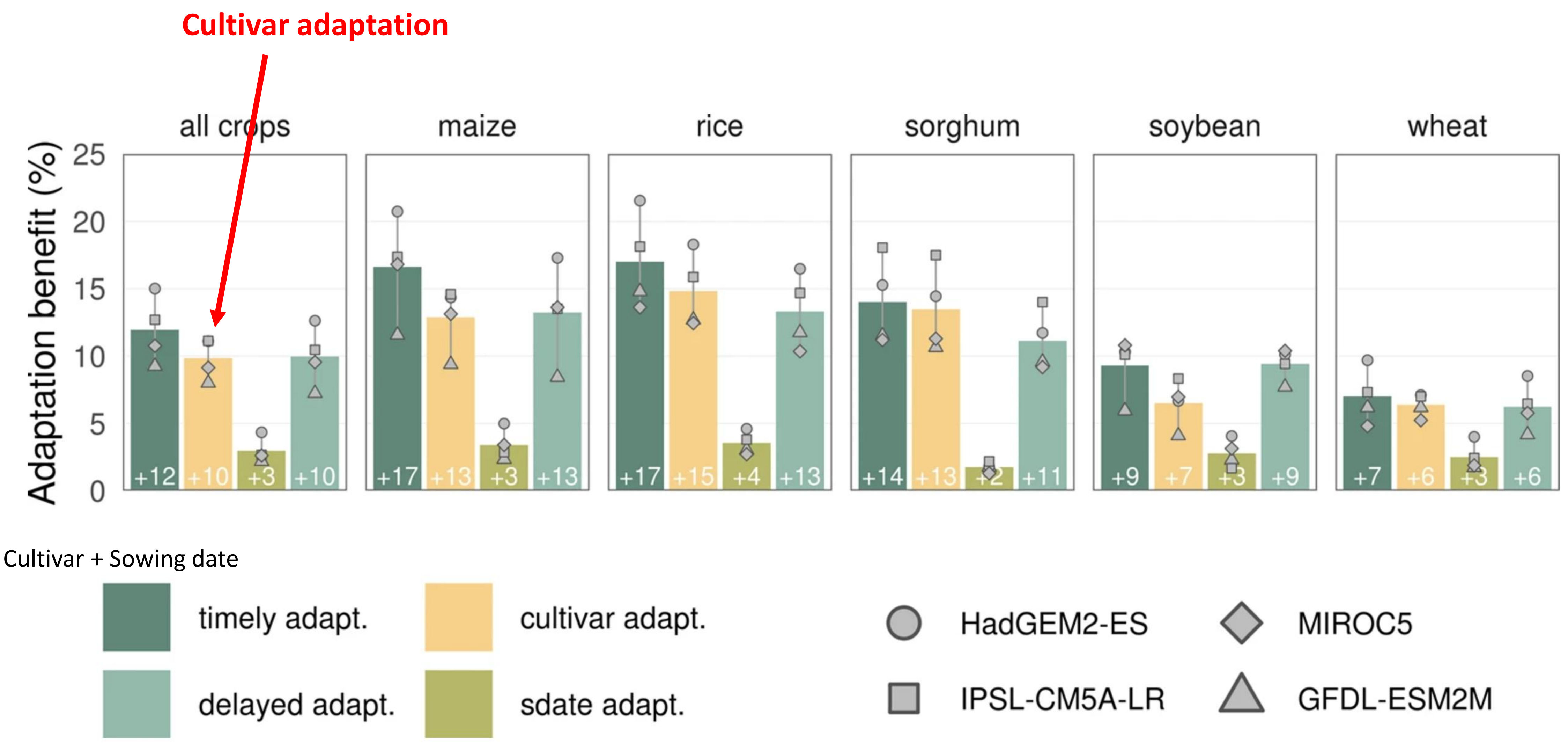
Received: 18 October 2021

Accepted: 25 October 2022

Sara Minoli[1] ✉, Jonas Jägermeyr[1,2,3], Senthold Asseng[4], Anton Urfels[5,6,7] & Christoph Müller[1]



Cultivar adaptation +
Sowing date adaptation
all crops
maize
rice
sorghum
soybean
wheat
Adaptation benefit (%)
25
20
15
10
5
0
+12 +10 +3 +10
+17 +13 +3 +13
+17 +15 +4 +13
+14 +13 +2 +11
+9 +7 +3 +9
+7 +6 +3 +6
Cultivar + Sowing date
timely adapt.
cultivar adapt.
delayed adapt.
sdate adapt.
HadGEM2-ES
MIROC5
IPSL-CM5A-LR
GFDL-ESM2M



Cultivar adaptation
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Adaptation benefit (%)
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+14
+13
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+11
+9
+7
+3
+9
+7
+6
+3
+6
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sdate adapt.
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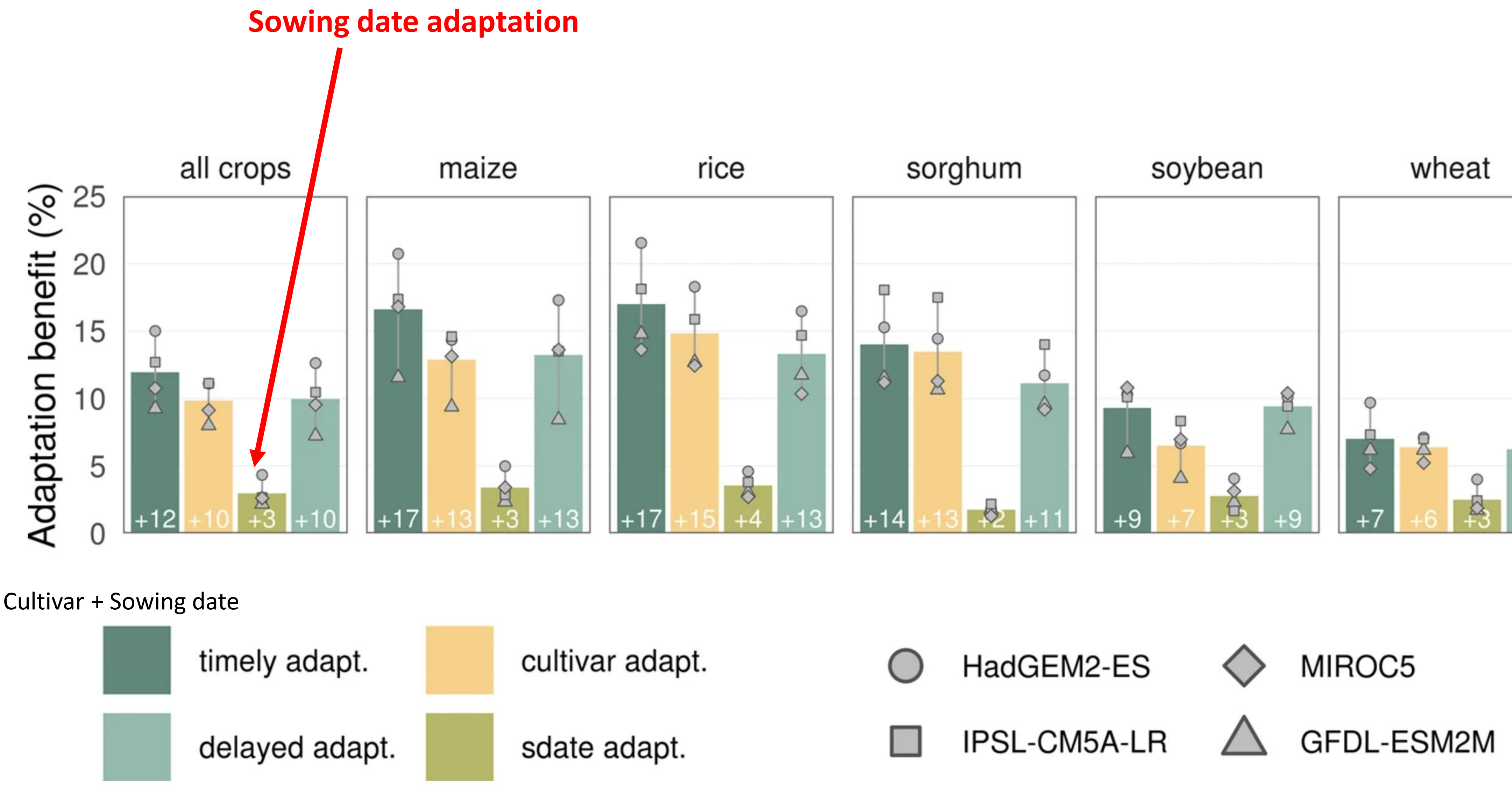
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wheat
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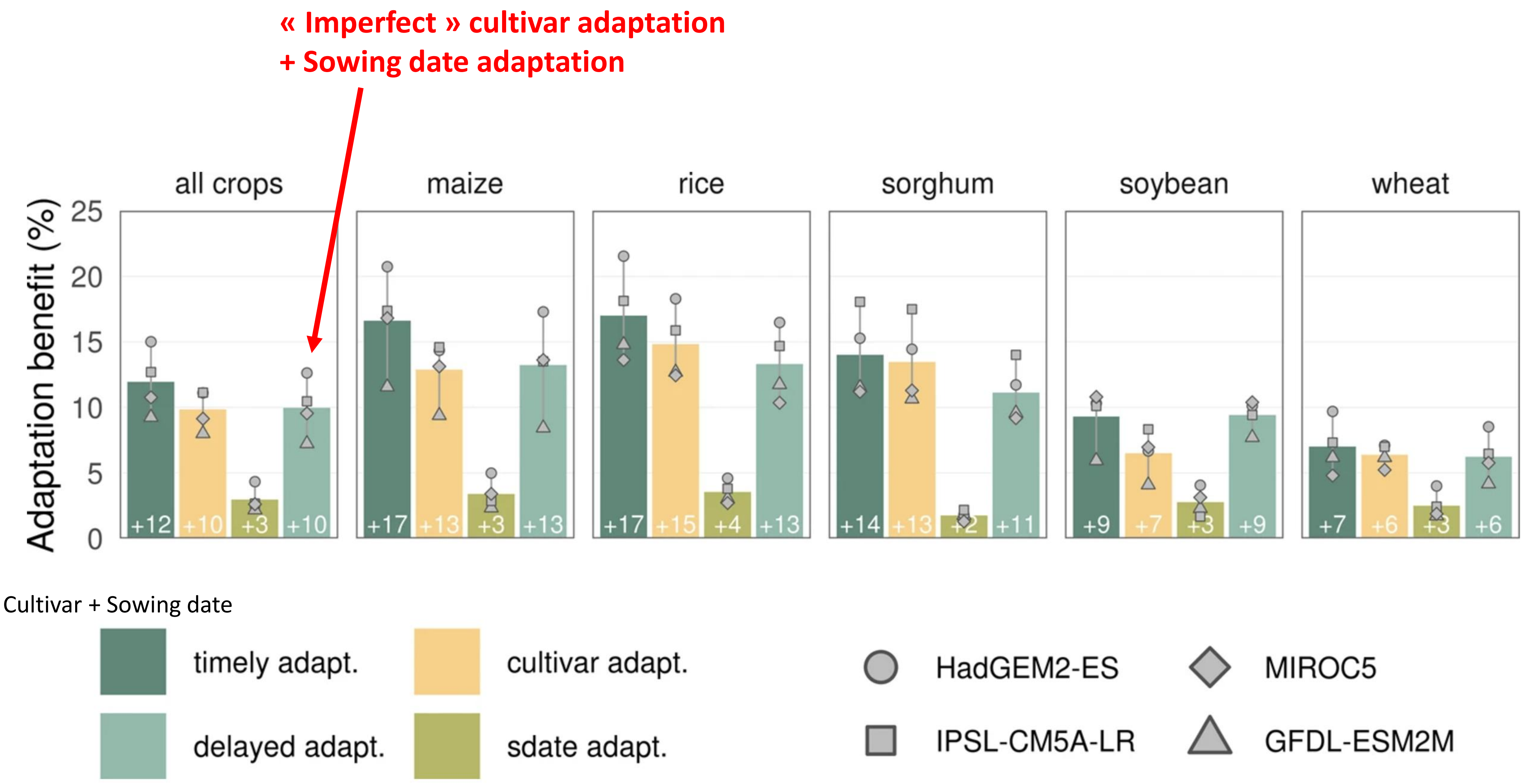
+17 +13 +3 +13
+17 +15 +4 +13
+14 +13 +2 +11
+9 +7 +3 +9
+7 +6 +3 +6
Cultivar + Sowing date
timely adapt.
cultivar adapt.
delayed adapt.
sdate adapt.
HadGEM2-ES
MIROC5
IPSL-CM5A-LR
GFDL-ESM2M


« Imperfect » cultivar adaptation
+ Sowing date adaptation
all crops
maize
rice
sorghum
soybean
wheat
Adaptation benefit (%)
25
20
15
10
5
0
+12 +10 +3 +10
+17 +13 +3 +13
+17 +15 +4 +13
+14 +13 +2 +11
+9 +7 +3 +9
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How to adapt cropping systems to climate change?

1. Crop migration/Crop substitution
2. Plant breeding/New cultivars
3. Sowing & harvest dates
4. **Irrigation**

nature climate change

Article https://doi.org/10.1038/s41558-022-01492-5

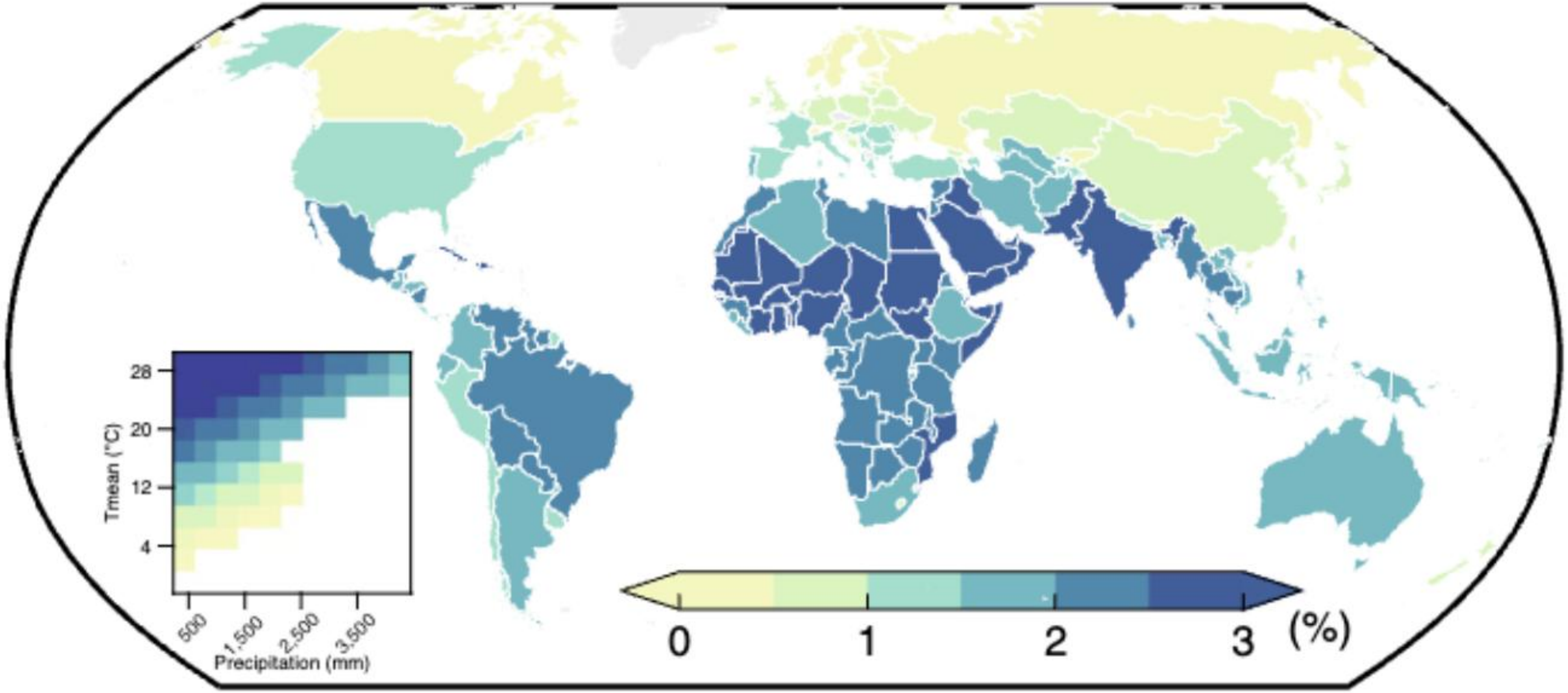
Warming reduces global agricultural production by decreasing cropping frequency and yields

Received: 4 September 2021

Accepted: 5 September 2022

Peng Zhu[1,2,3], Jennifer Burney[4], Jinfeng Chang[5], Zhenong Jin[6], Nathaniel D. Mueller[7,8], Qinchuan Xin[3], Jialu Xu[9], Le Yu[10,11], David Makowski[12] and Philippe Ciais[1]

Effect of +1% of irrigated land on the crop productivity



DESERT DURUM®

Desert Durum® Continues To Deliver Consistently Excellent Quality

Arizona, Texas, California

Arizona Desert Durum® variety trial plots.

Almond production in California

https://agnetwest.com/california-almond-acreage-sees-first-decline-in-over-two-decades/

Rivières asséchées suite au détournement de l’eau pour l’irrigation. Nord-est de la Chine. L’année 2025 est pourtant considérée comme très pluvieuse.

Photo. David Makowski 2025

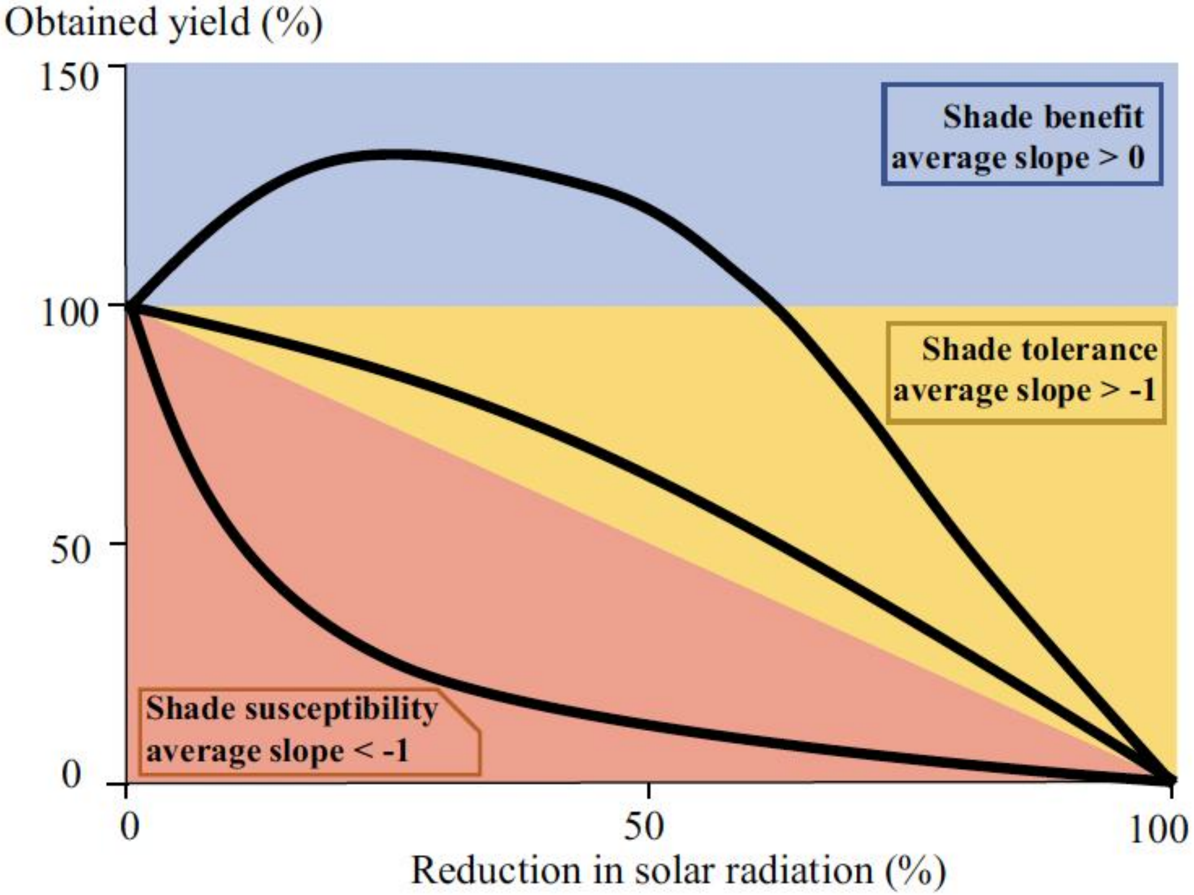
Irrigation du riz avec l'eau détournée des rivières. Nord-est de la Chine. Sur le même site, l'eau est également utilisée pour des cultures maraichères, notamment pour produire des pastèques.

Photo. David Makowski 2025

How to adapt cropping systems to climate change?

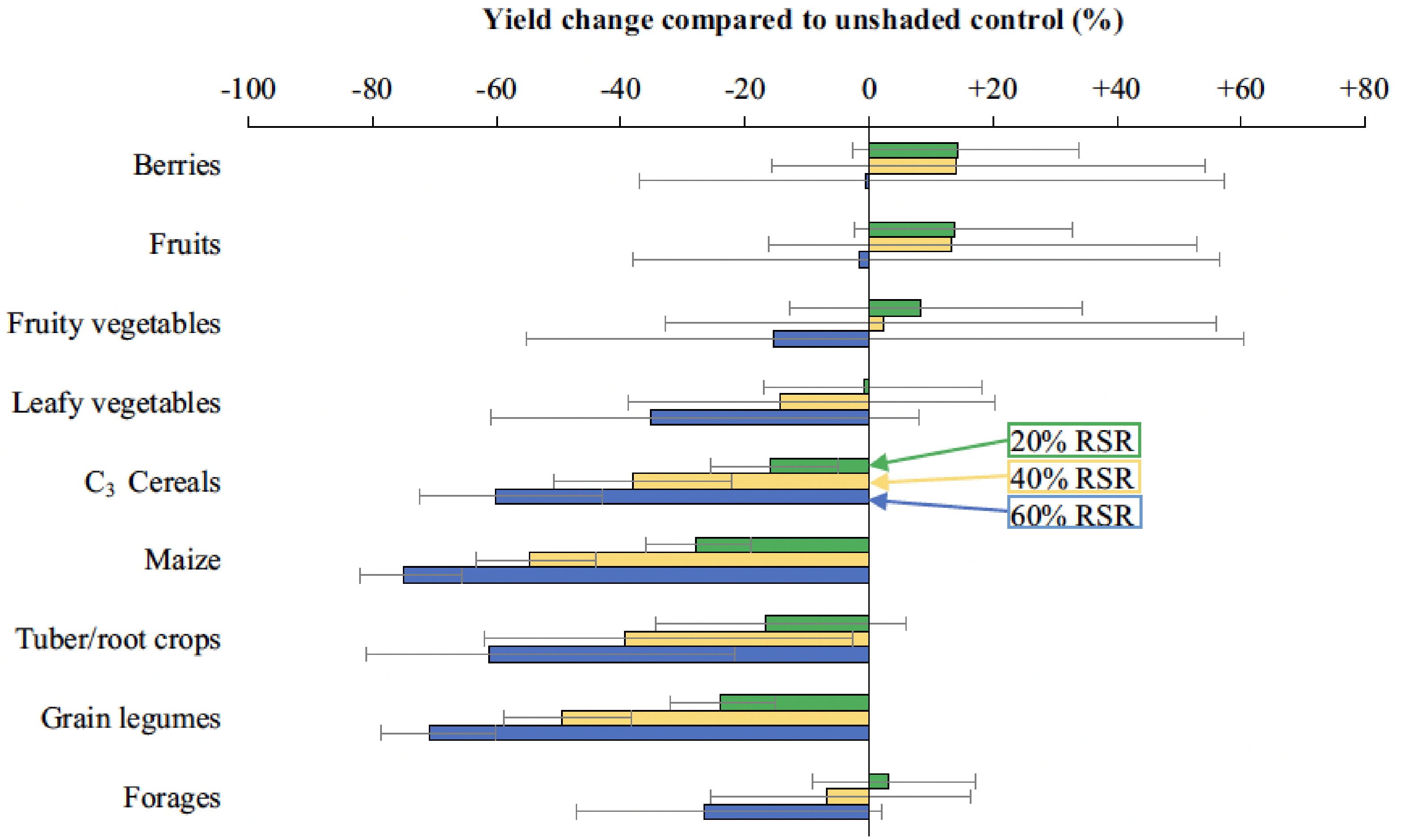
1. Crop migration/Crop substitution
2. Plant breeding/New cultivars
3. Sowing & harvest dates
4. Irrigation
5. **Shading**

Fig. 1 Shaded winter wheat in an agrivoltaic system in Germany (Photograph by Lisa Pataczek).



https://doi.org/10.1007/s13593-022-00783-7

Fig. 4 Yield responses of different crop types to varying levels of reduction in solar radiation (RSR). Displayed are the least square means. Error bars delimit the 95% confidence intervals of the true mean. Within the same level of RSR, crop types with non-overlapping confidence intervals are significantly different ($p<0.05$).



https://doi.org/10.1007/s13593-022-00783-7

How to adapt cropping systems to climate change?

1. Crop migration/Crop substitution
2. Plant breeding/New cultivars
3. Sowing & harvest dates
4. Irrigation
5. Shading
6. **Double cropping**

Soybean-corn double cropping in Brazil

https://doi.org/10.1038/s43016-021-00255-3

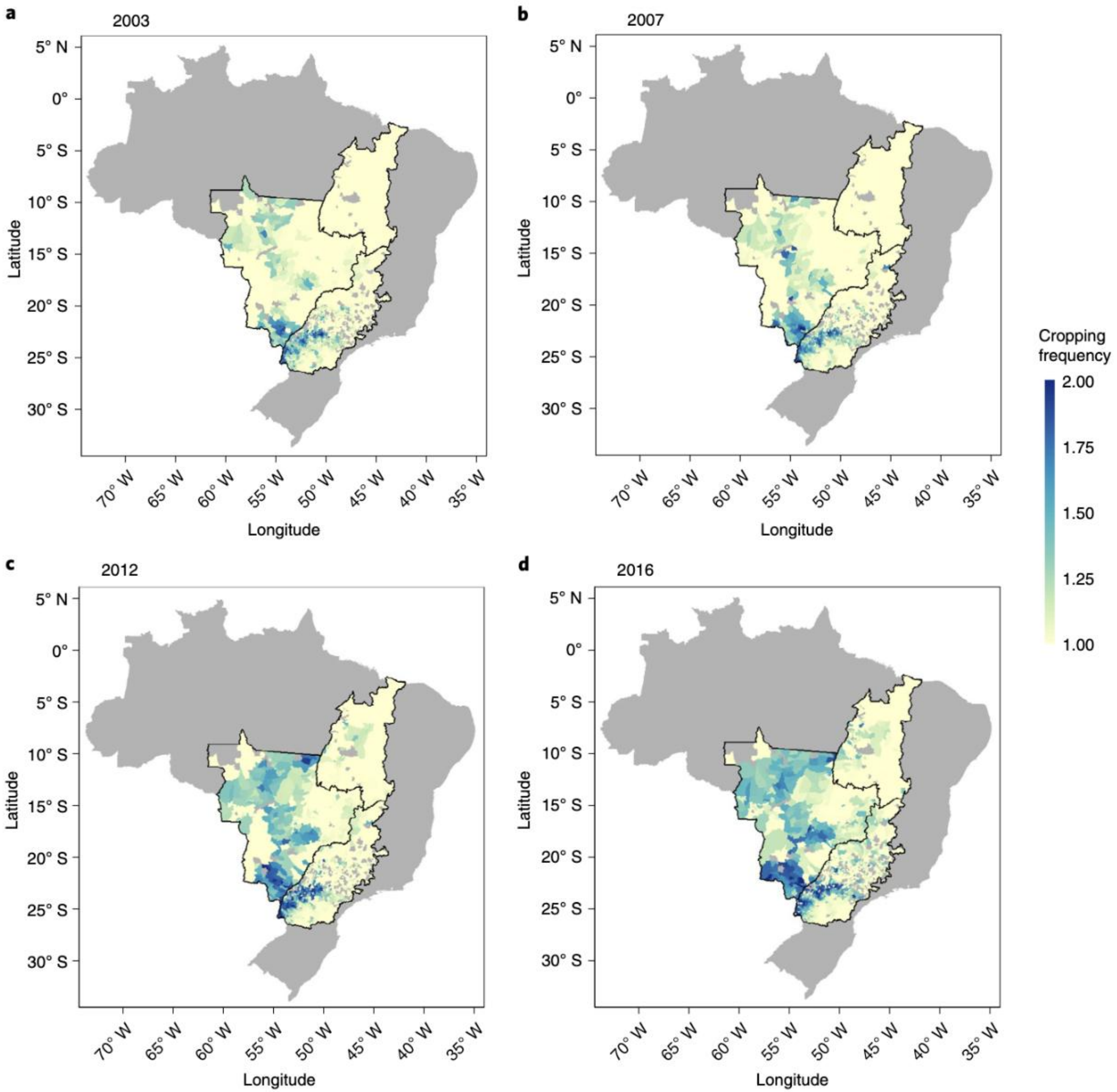


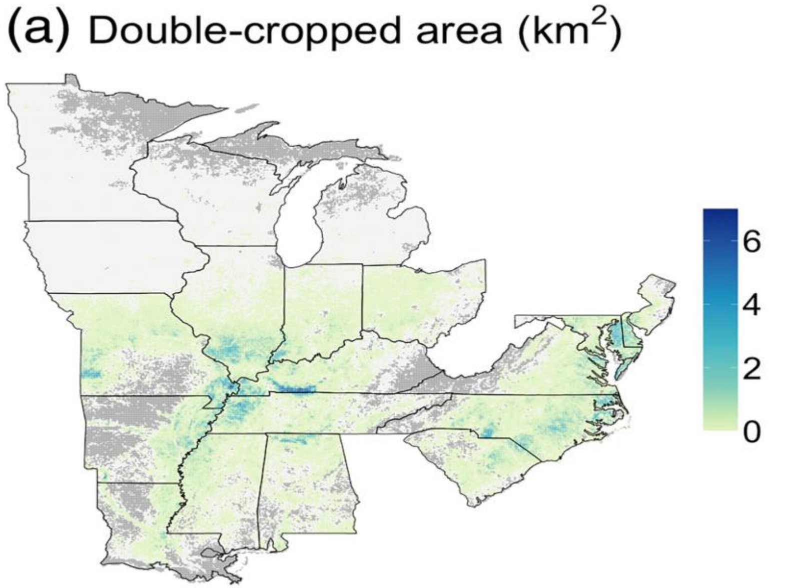
Fig. 6 | Cropping frequency of soybean and corn systems in the key agricultural regions of Brazil. a–d, County-level cropping frequency in the years 2003 (**a**), 2007 (**b**), 2012 (**c**) and 2016 (**d**). Black lines demarcate the borders of the three key regions.

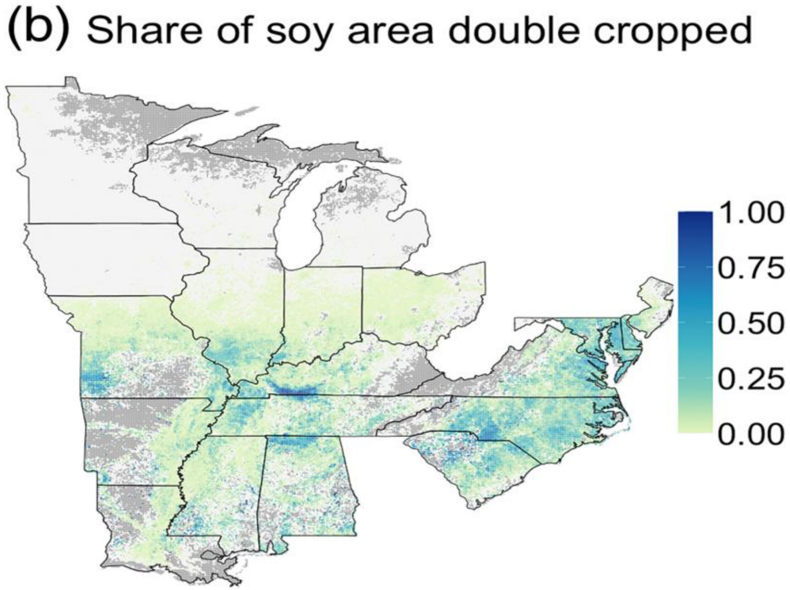
Double cropping (wheat-soy) as an adaptation to climate change in the United States

Crop combination	Mean area (km^2)	Share of all DC
Winter wheat–soybeans	16,964	0.75
Winter wheat–corn	1394	0.06
Winter wheat–sorghum	1372	0.06
Winter wheat–cotton	852	0.04
Triticale–corn	689	0.03
Oats–corn	403	0.02
Barley–soybeans	300	0.01
Other combinations	432	0.02

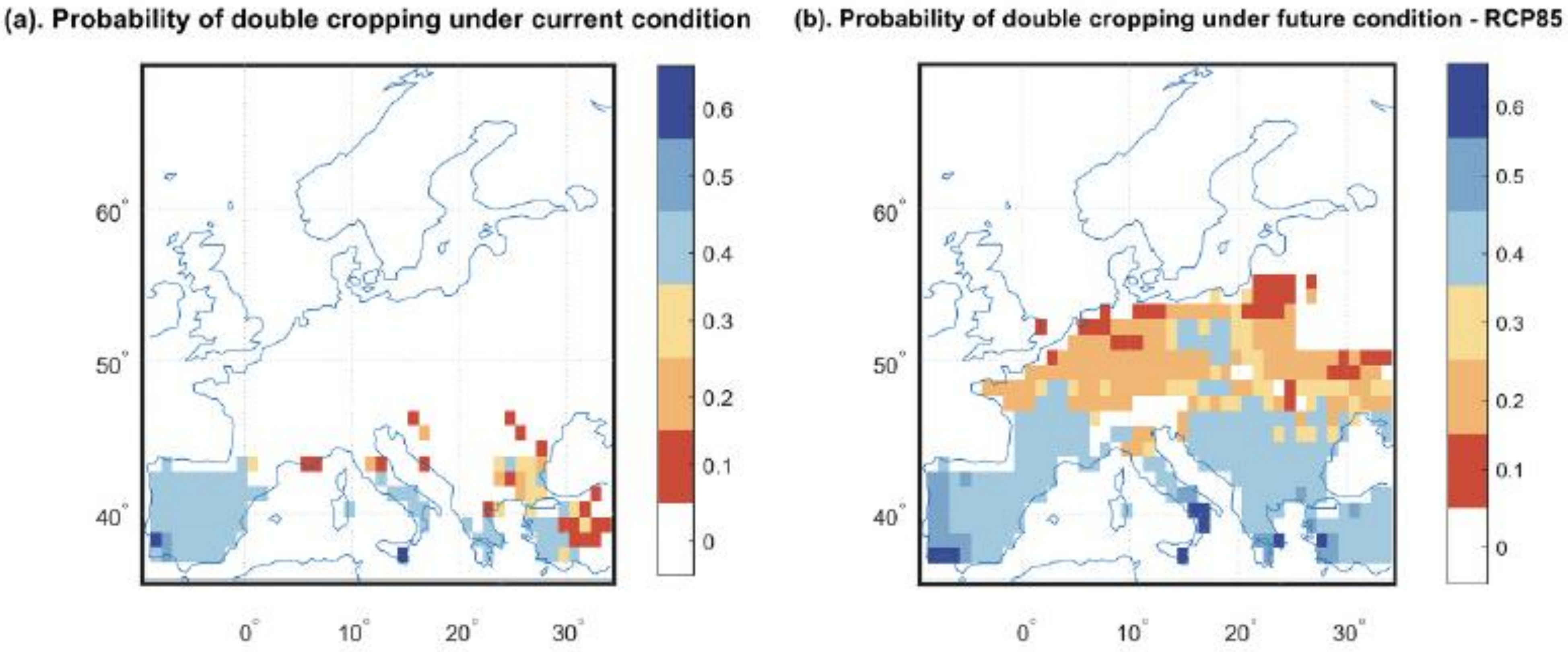
Note: Authors' calculations based on 2008–2022 data from the Cropland Data Layer.

American J Agri Economics, First published: 21 August 2024, DOI: (10.1111/ajae.12491)





Double cropping (wheat-maize) as an adaptation to climate change in Europe



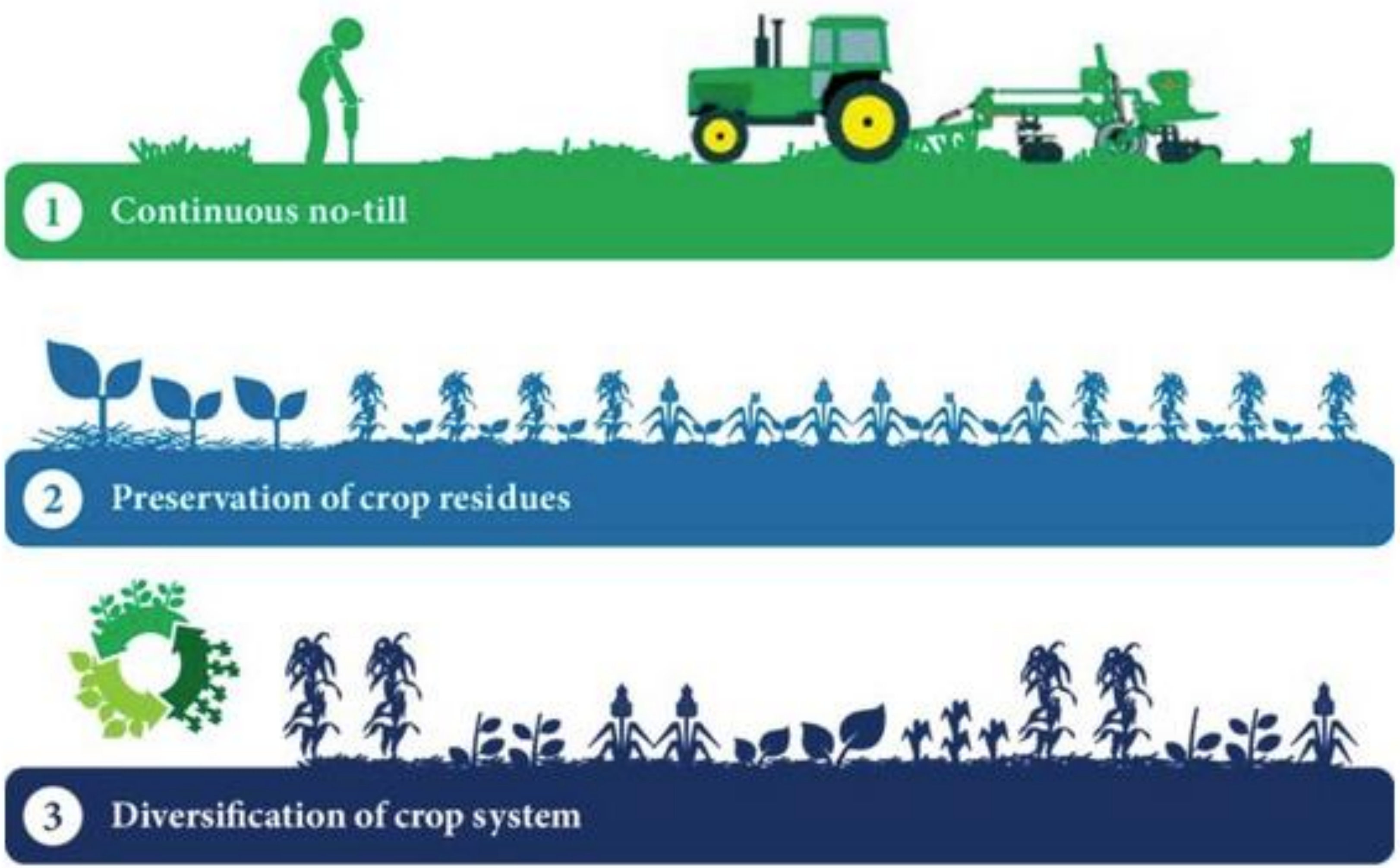
https://doi.org/10.1016/j.eja.2025.127723

How to adapt cropping systems to climate change?

1. Crop migration/Crop substitution
2. Plant breeding/New cultivars
3. Sowing & harvest dates
4. Irrigation
5. Shading
6. Double cropping
7. **Combination of strategies**

Conservation agriculture

FAOISBN: 978-92-5-131456-2



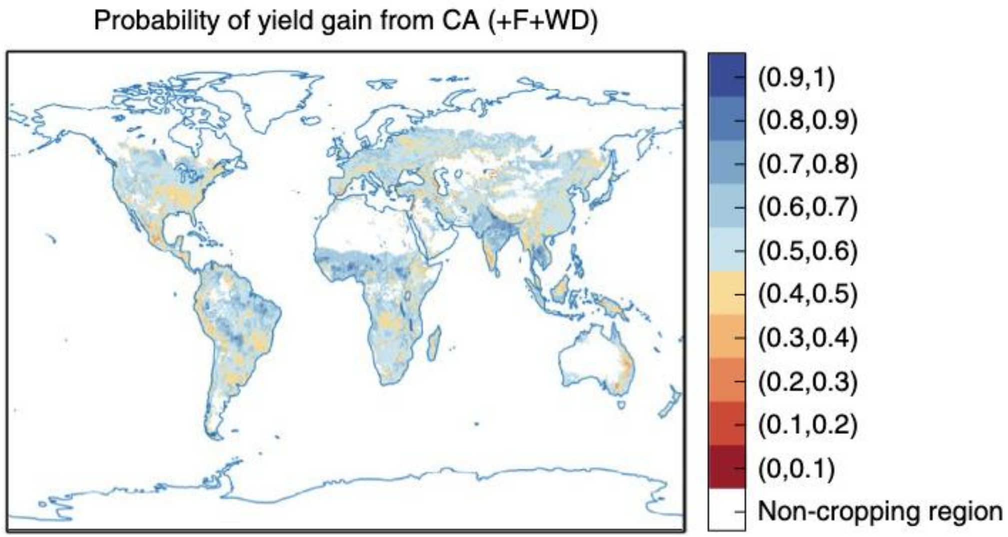
Probability of yield gain CA *vs.* CA for maize

Future climate (RCP4.5 2051-2060)

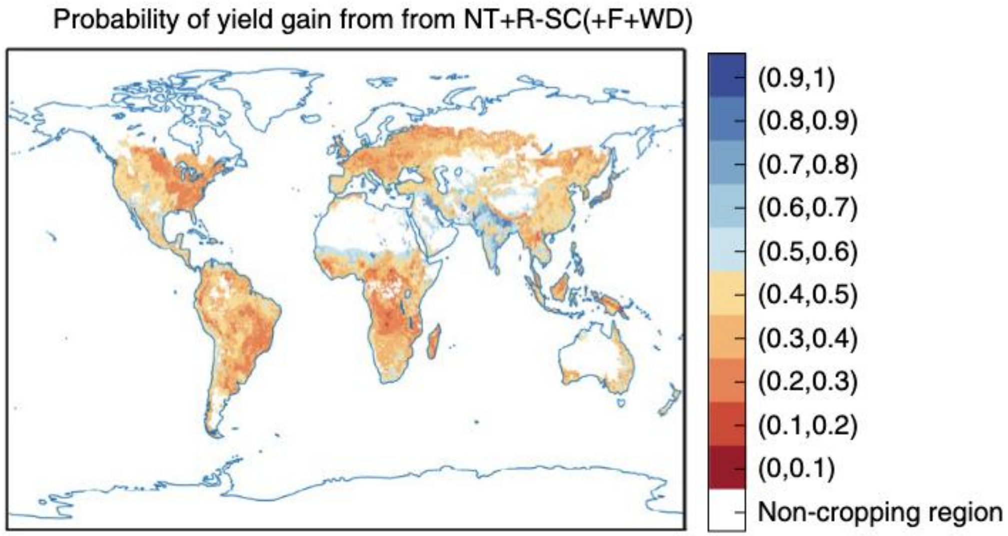
https://doi.org/10.1038/s41558-021-01075-w

CA=conservation agriculture
NT=no-tillage
SC=Soil cover
R=rotation
F=fertilization
WD=weed control

a



c



https://doi.org/10.1038/s41558-021-01075-w

Probability of yield gain CA *vs.* CA for maize

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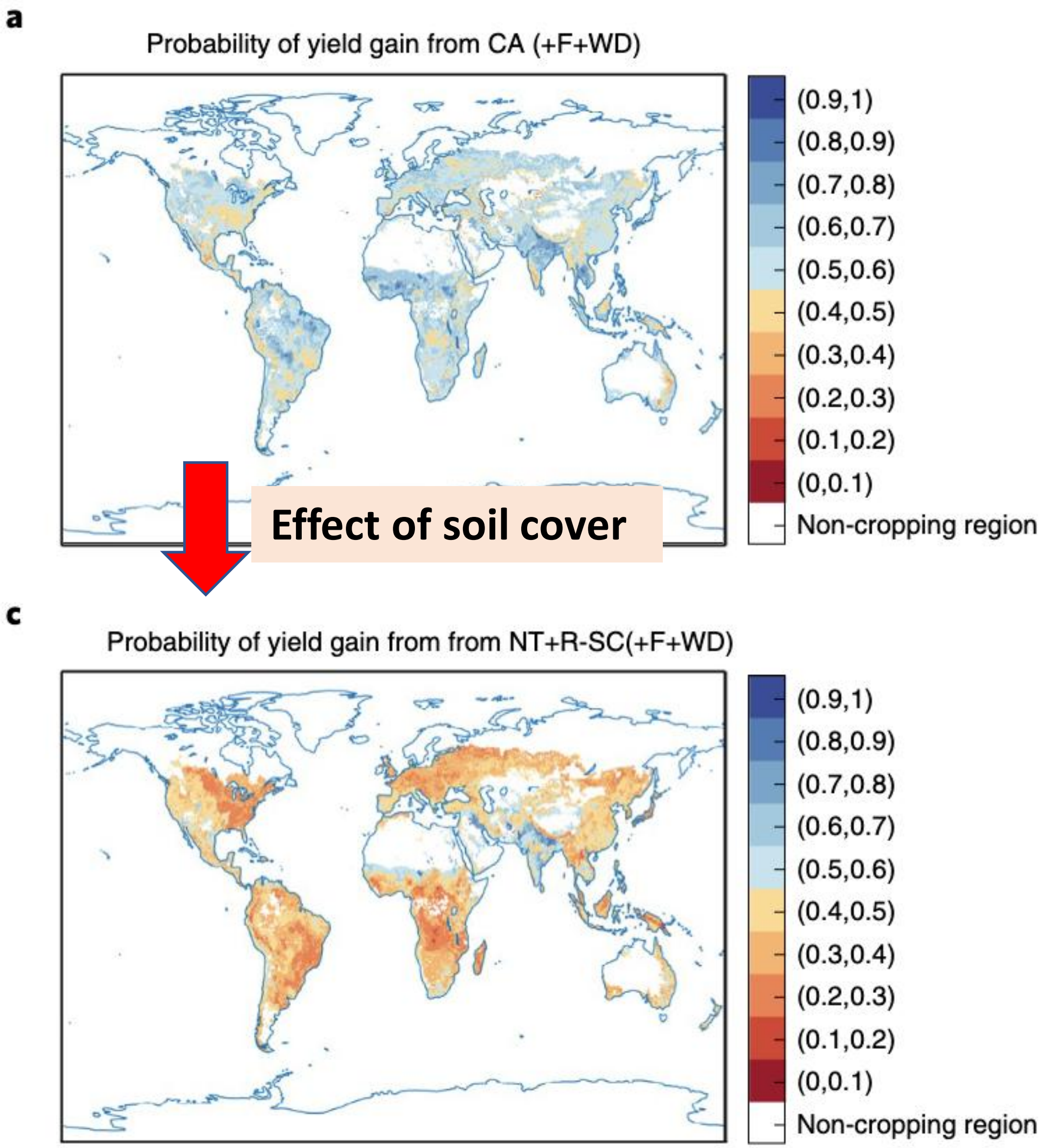
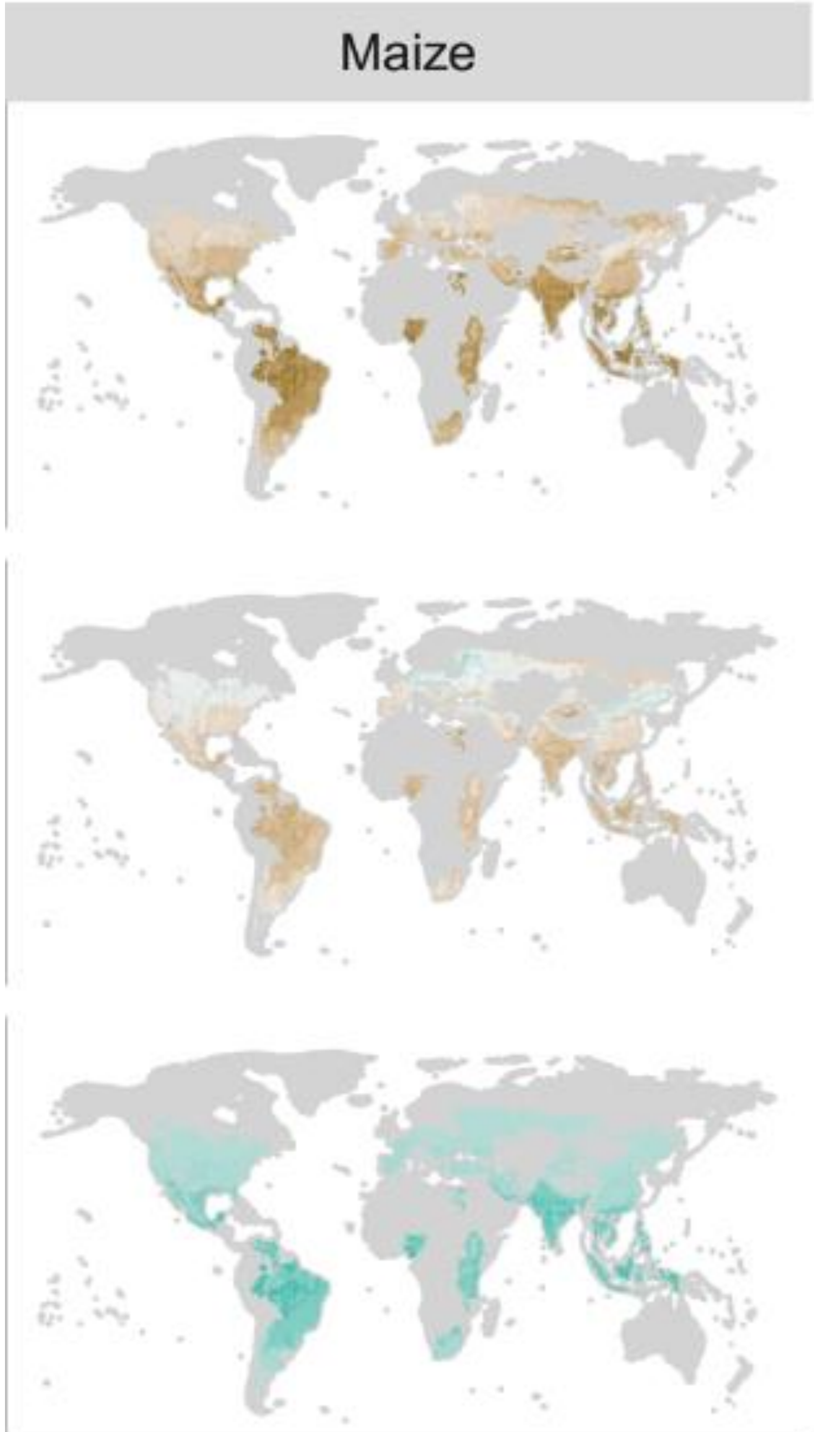


Does it work?

RCP 4.5 mid century

https://doi.org/10.1029/2022EF003190



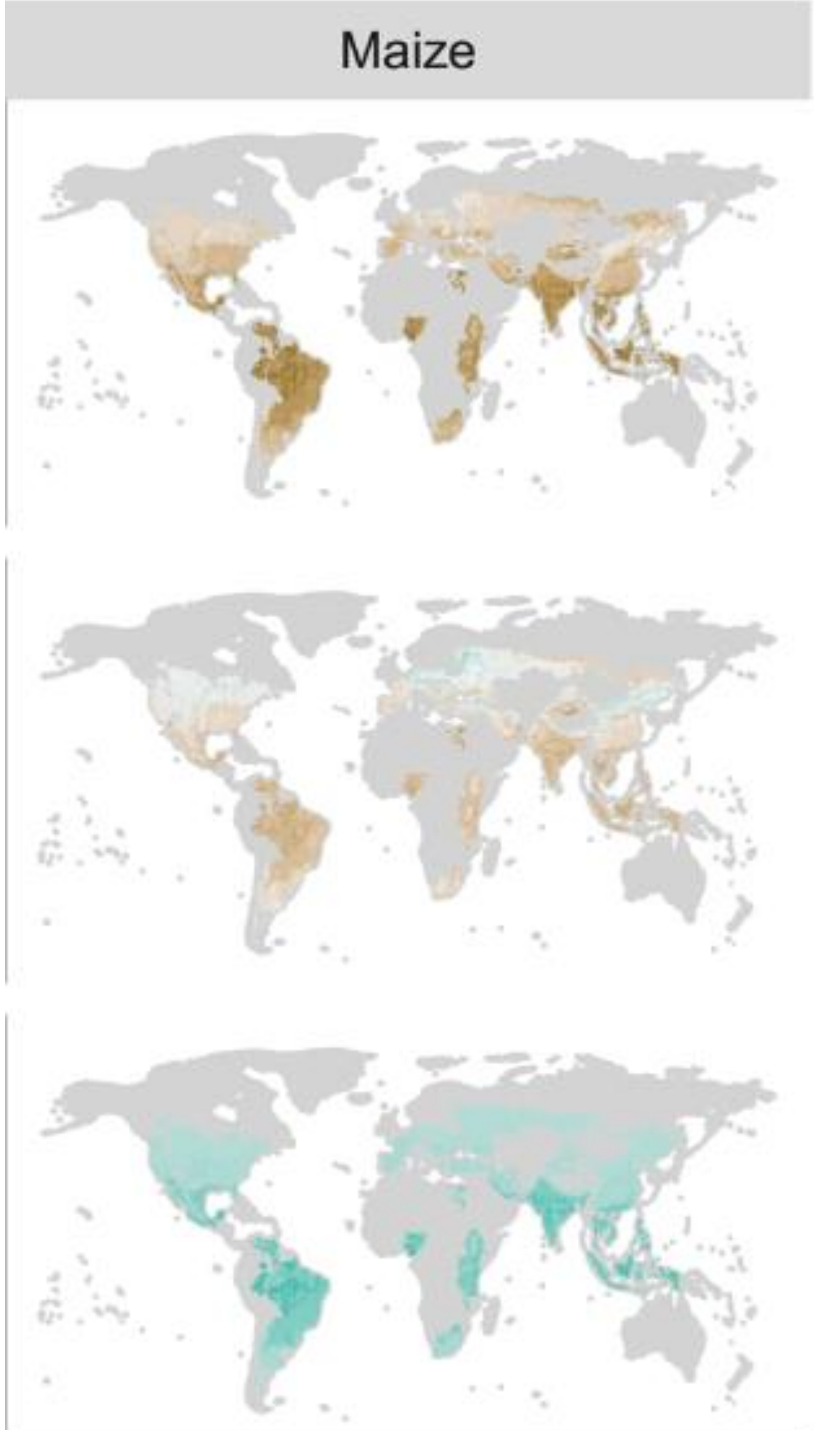
No adaptation

Adaptation

Adaptation vs. No adaptation

https://doi.org/10.1029/2022EF003190

Yield losses almost everywhere without adaptation

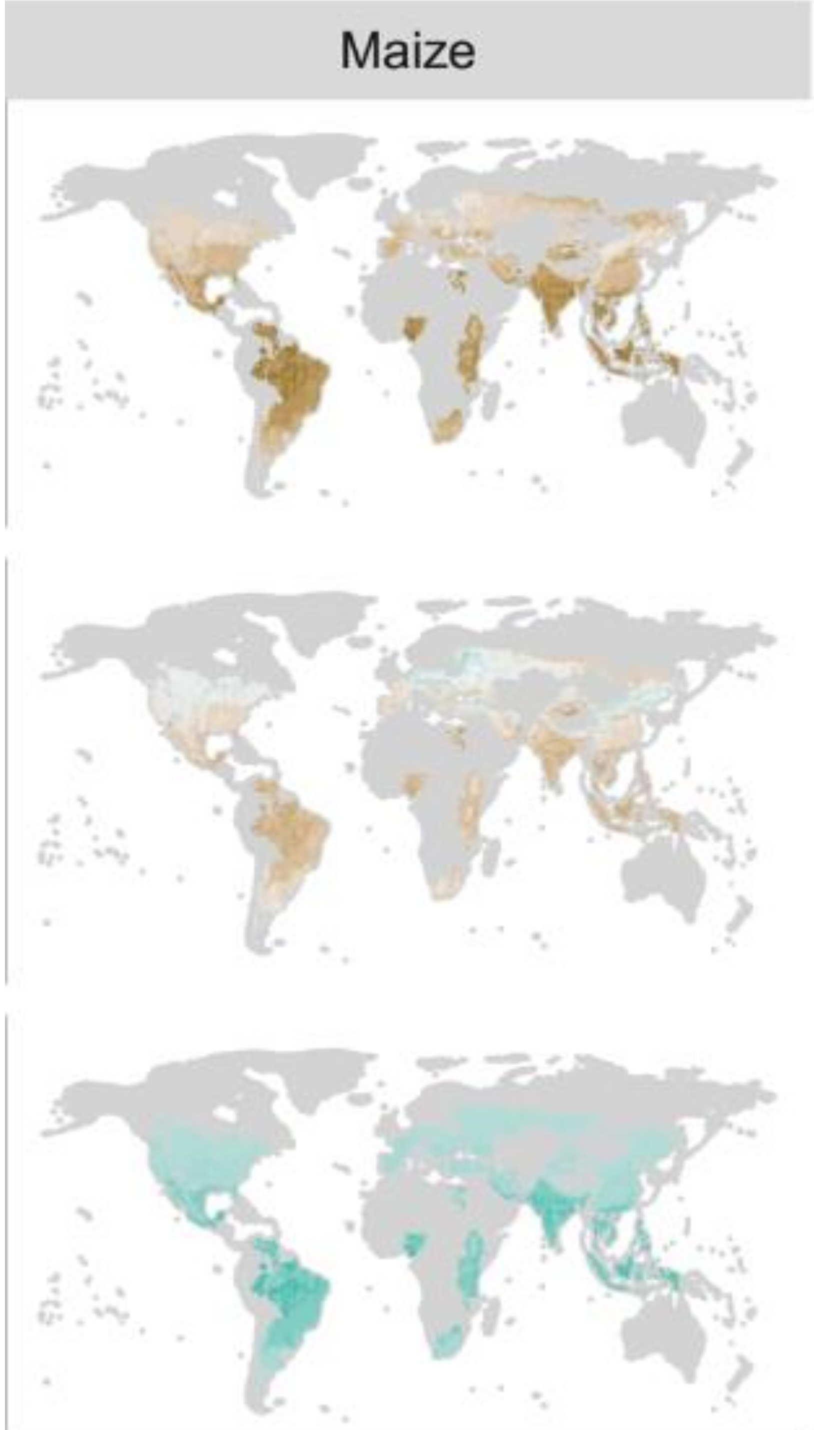


No adaptation

Adaptation

Adaptation vs. No adaptation

https://doi.org/10.1029/2022EF003190



No adaptation

Adaptation

Adaptation vs. No adaptation

Positive impact of the adaptation strategies leading sometimes to yield gains

Does it work?

Table 1 | Projected change in staple crop yields owing to climate change

		Change in 2050 (% yield)		Change in 2098 (% yield)	
		1a Producer behaviour unchanged	**1b Accounting for adaptation and development**	**2a Producer behaviour unchanged**	**2b Accounting for adaptation and development**
World	RCP 8.5	−10.1	−7.8	−36.6	−24.0
	RCP 4.5	*−8.3*	*−7.8*	*−12.7*	*−11.2*

https://doi.org/10.1038/s41586-025-09085-w

Does it work?

Table 1 | Projected change in staple crop yields owing to climate change

		Change in 2050 (% yield)		Change in 2098 (% yield)	
		1a Producer behaviour unchanged	1b Accounting for adaptation and development	2a Producer behaviour unchanged	2b Accounting for adaptation and development
World	RCP 8.5	−10.1	−7.8	−36.6	−24.0
	RCP 4.5	−8.3	−7.8	−12.7	−11.2

https://doi.org/10.1038/s41586-025-09085-w

Lower yield losses with adaptation

Conclusions

- Many risks, but opportunities exist.
- Large range of adaptation strategies:
  - ➢Crop migration/Crop substitution
  - ➢Plant breeding/New cultivars
  - ➢Sowing & harvest dates
  - ➢Irrigation
  - ➢Shading
  - ➢Cropping systems
- Adaptation strategies can (partly) mitigate negative impacts of climate change