CLAND AG
2022

Adaptation strategies strongly reduce the future impacts of climate change on crop yields

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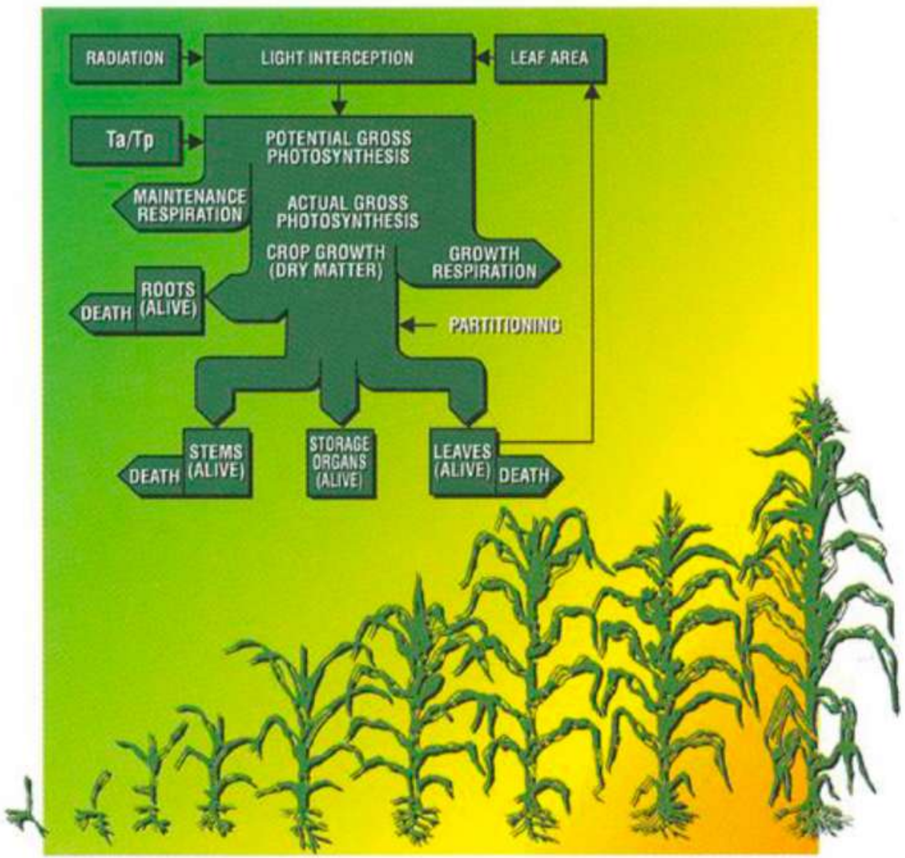
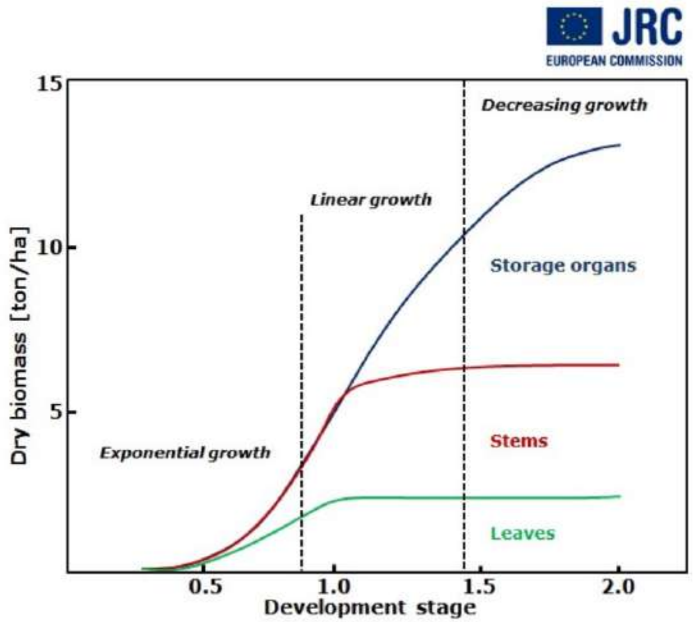
Context

- Future yields under climate change can be projected using either statistical or process-based models that relate the climate, environment and management practices to plant production and crop yield.
- Simulations of crop yield due to climate change vary widely between models, locations, species, management strategies, and Representative Concentration Pathways (RCPs)
- It is therefore necessary to better understand the conditions leading to positive or negative impacts of climate change on the yields of major crops.

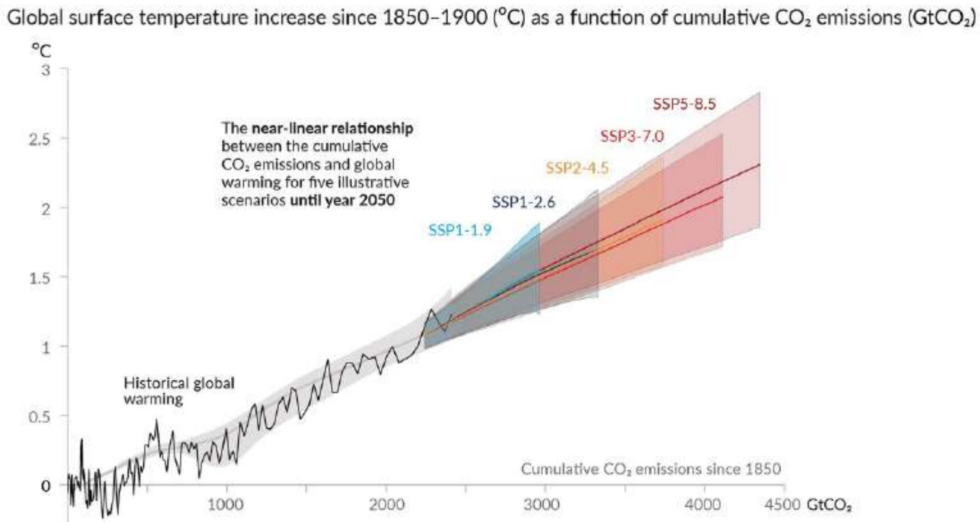
WOFOST Control Centre 2.1 and WOFOST 7.1.7

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

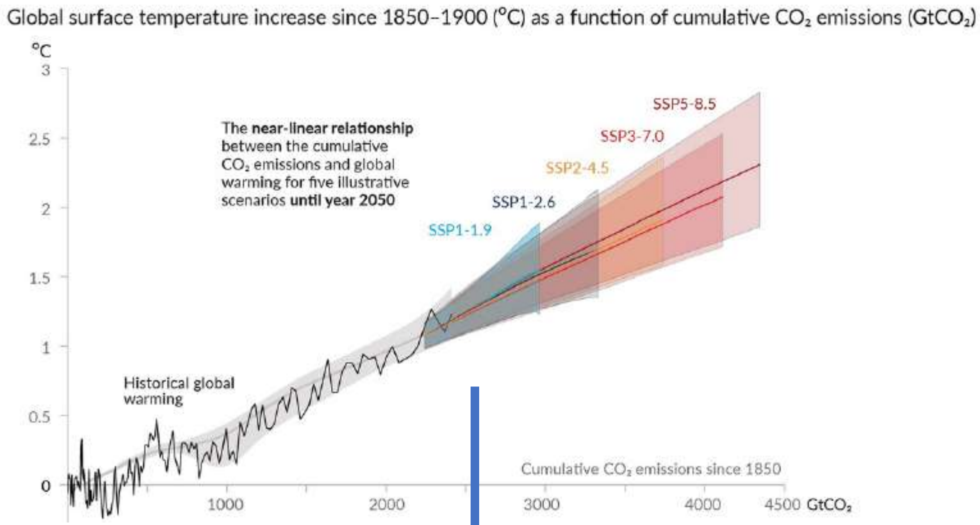




Shared socio-economic pathway



Shared socio-economic pathway

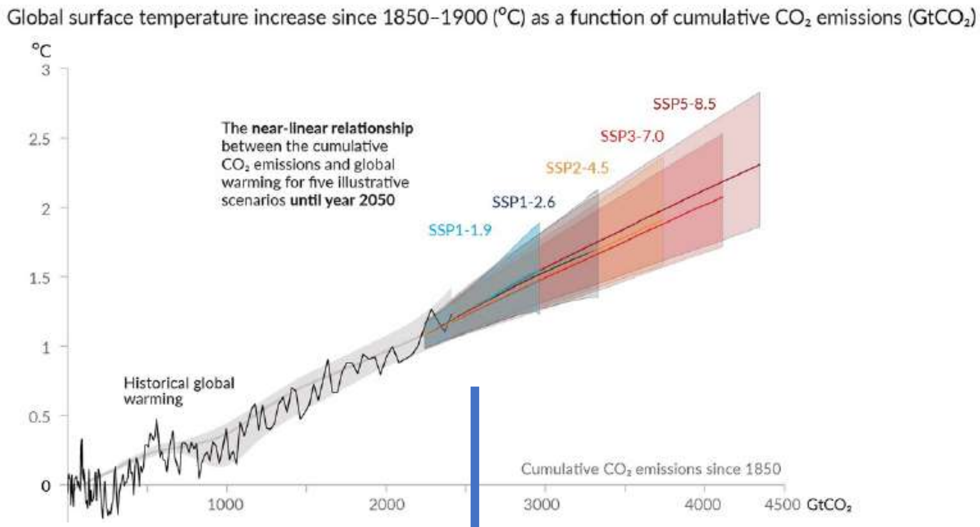


Climate conditions at specific locations

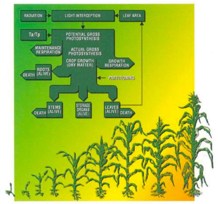
Weather inputs

- Temperatures
- Radiations
- Rainfall etc.

Shared socio-economic pathway



Crop model

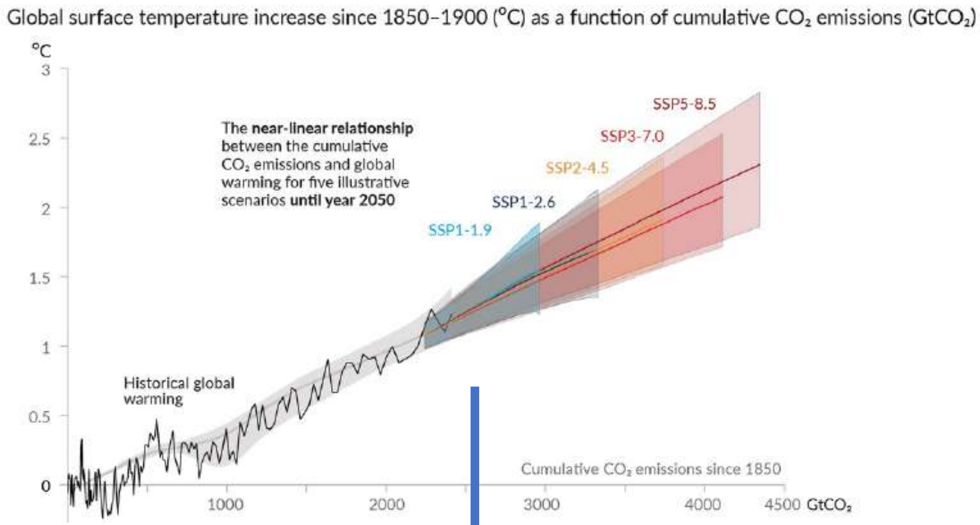


Climate conditions at specific locations

Weather inputs
- Temperatures
- Radiations
- Rainfall etc.

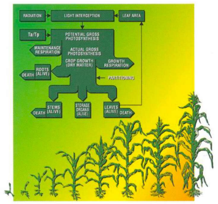
Other inputs
- Soil
- Farm practices
- Cultivar

Shared socio-economic pathway



Climate conditions at specific locations

Crop model



- Crop yield
- Biomass
- Leaf area
- N content

Etc.

Weather inputs

- Temperatures
- Radiations
- Rainfall etc.

Other inputs

- Soil
- Farm practices
- Cultivar

Objective

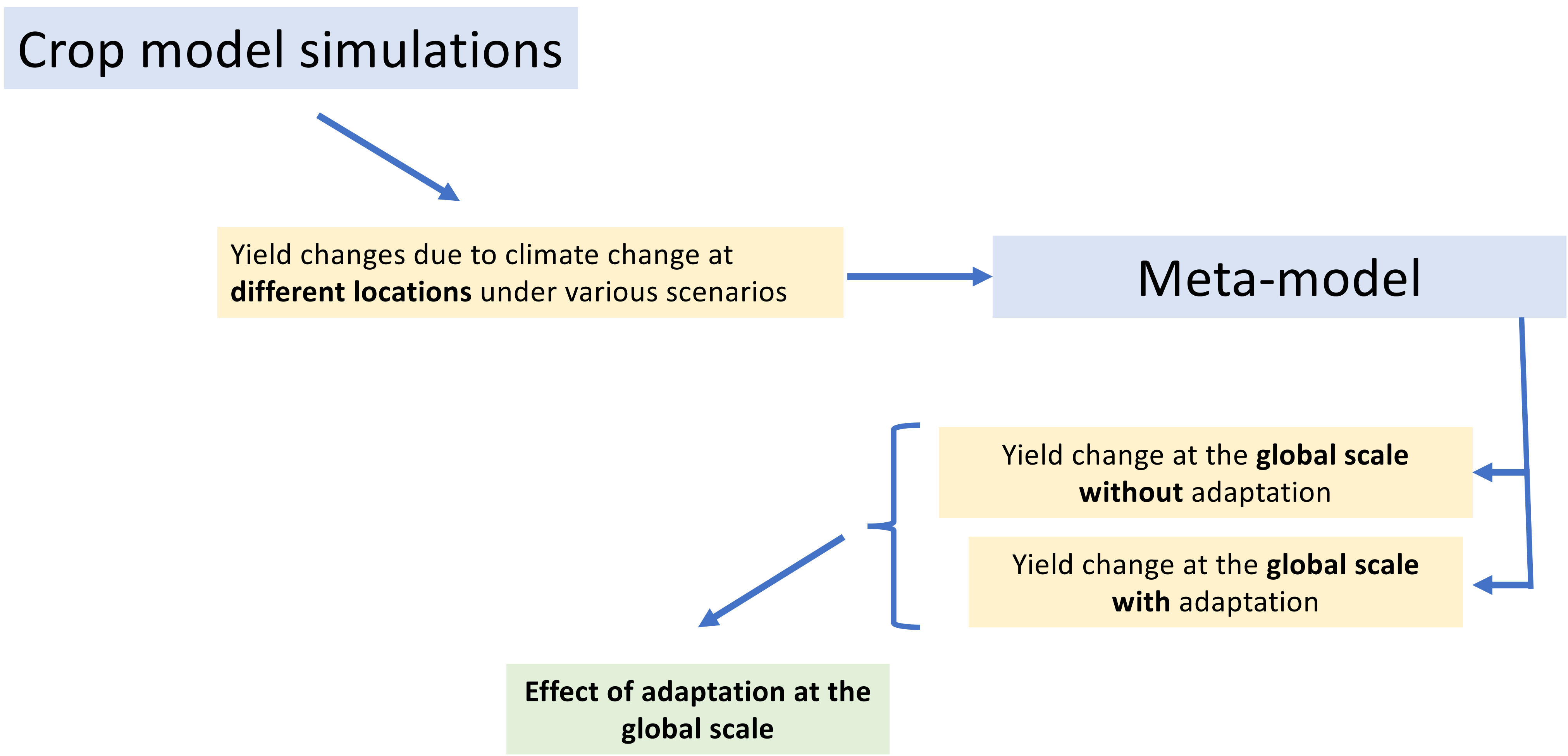
Use information from multiple model simulations in different locations to build global meta-models and use them to map the effect of climate change on crop yields at the global scale.

Research questions:

(1) What distributions of yield losses and gains can be expected on a global scale based on all the available agricultural model simulations?

(2) What are the most important factors explaining variability in yield change projections?

(3) To what extent are adaptation strategies able to mitigate yield losses?


Crop model simulations
Yield changes due to climate change at **different locations** under various scenarios
Meta-model
Yield change at the **global scale** **without** adaptation
Yield change at the **global scale** **with** adaptation
Effect of adaptation at the global scale

Data

https://doi.org/10.1038/s41597-022-01150-7

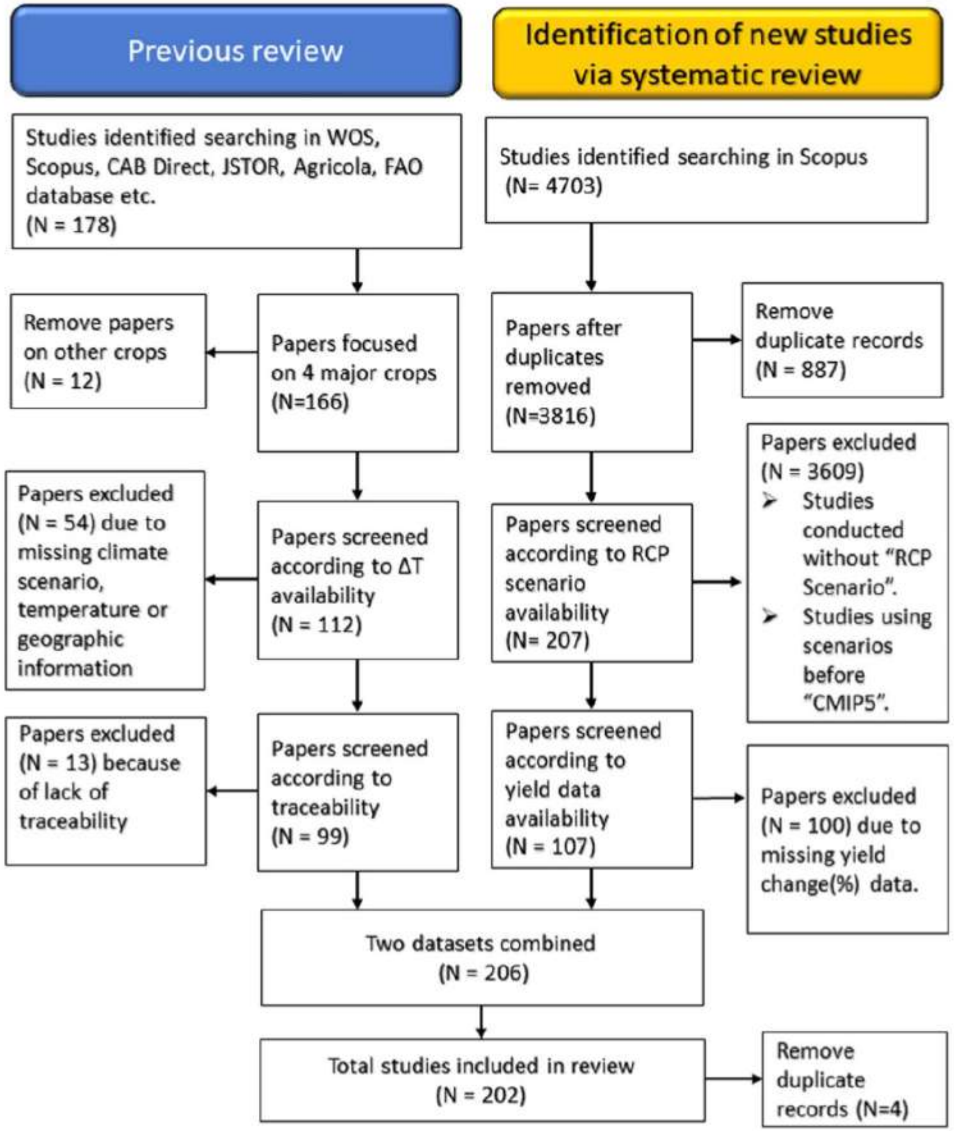
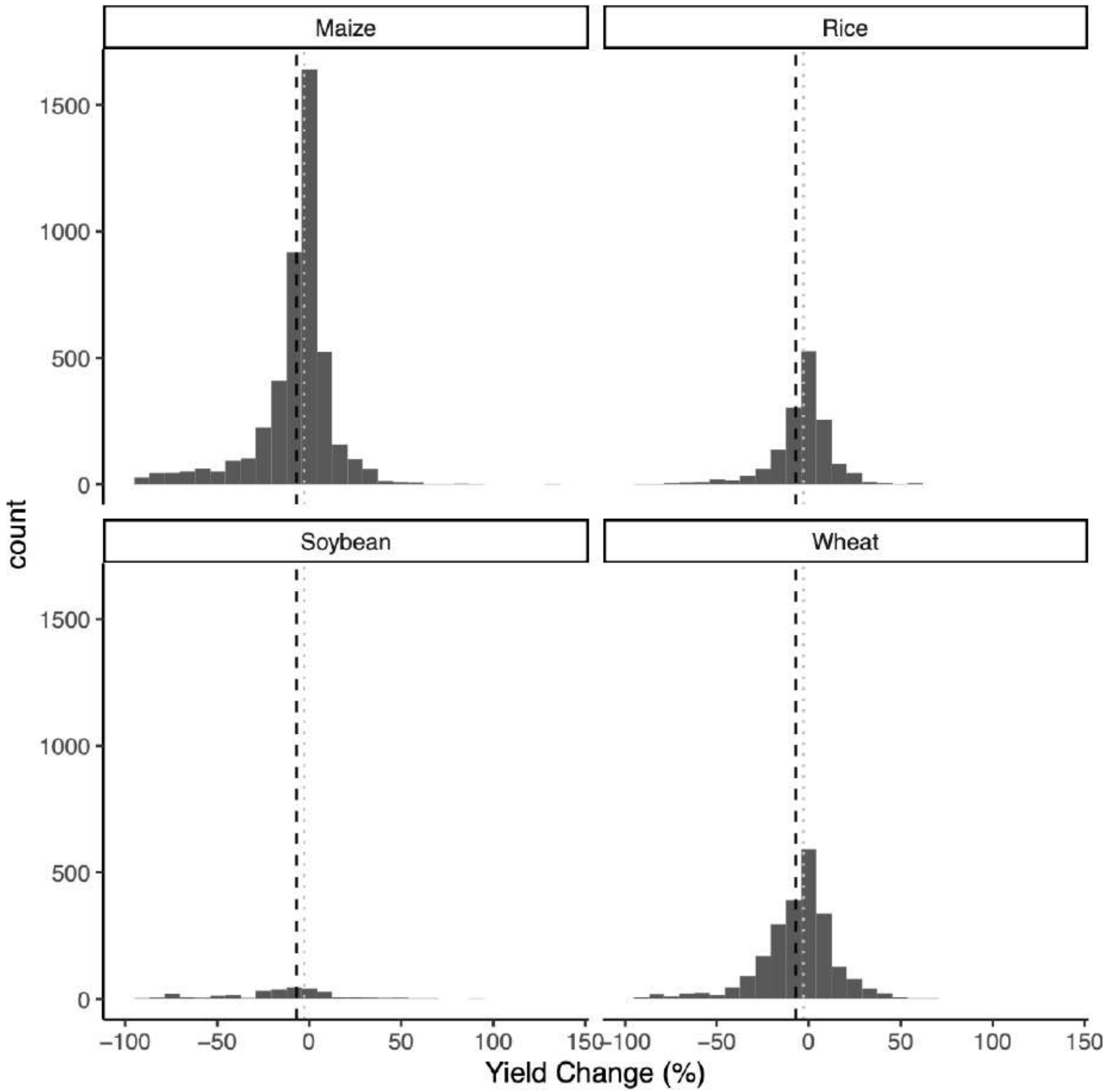
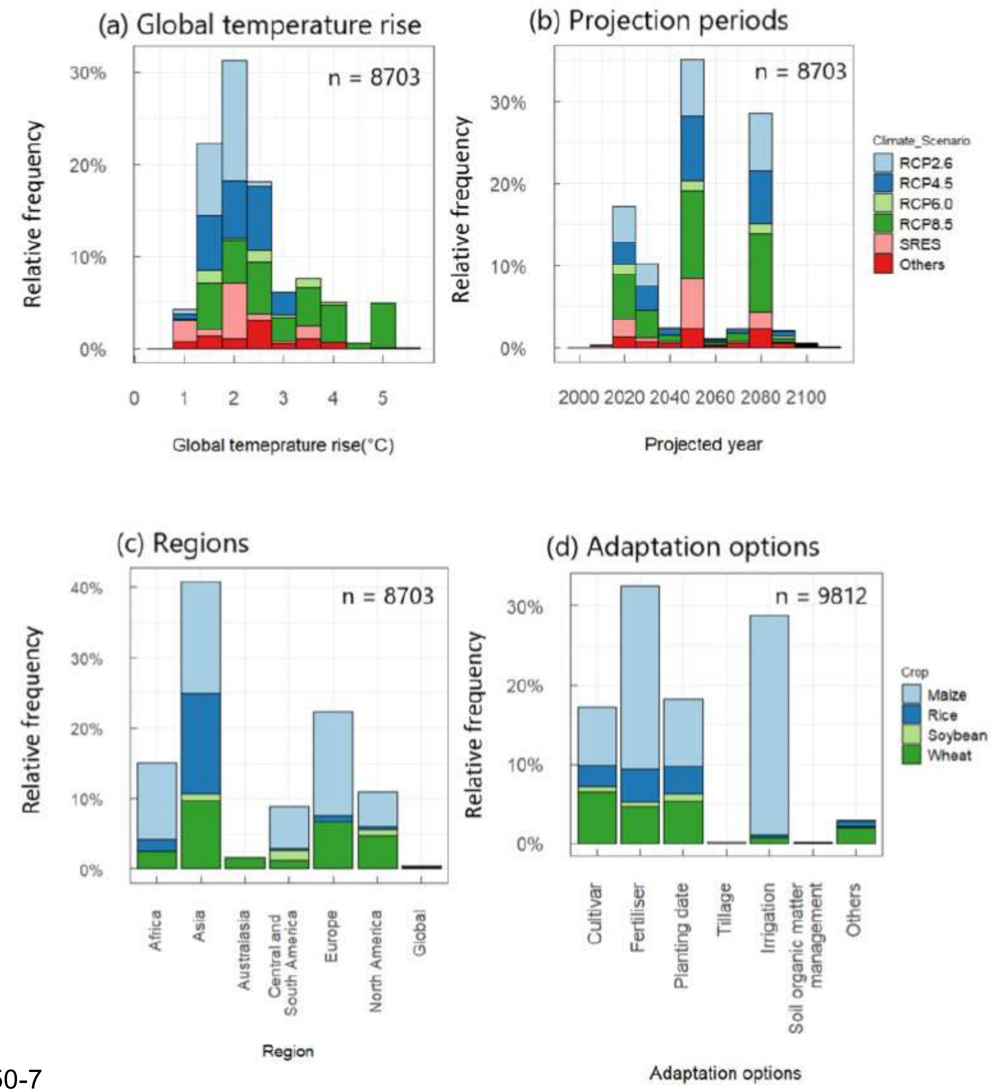


Fig. 1 A diagram depicting paper collection and selection using the two search strategies. N is the number of studies.



Crop	**Number of yield simulations**	**Number of locations**
Maize	4589	194
Rice	1519	99
Wheat	2298	174
Soybean	297	53

https://doi.org/10.1038/s41597-022-01150-7



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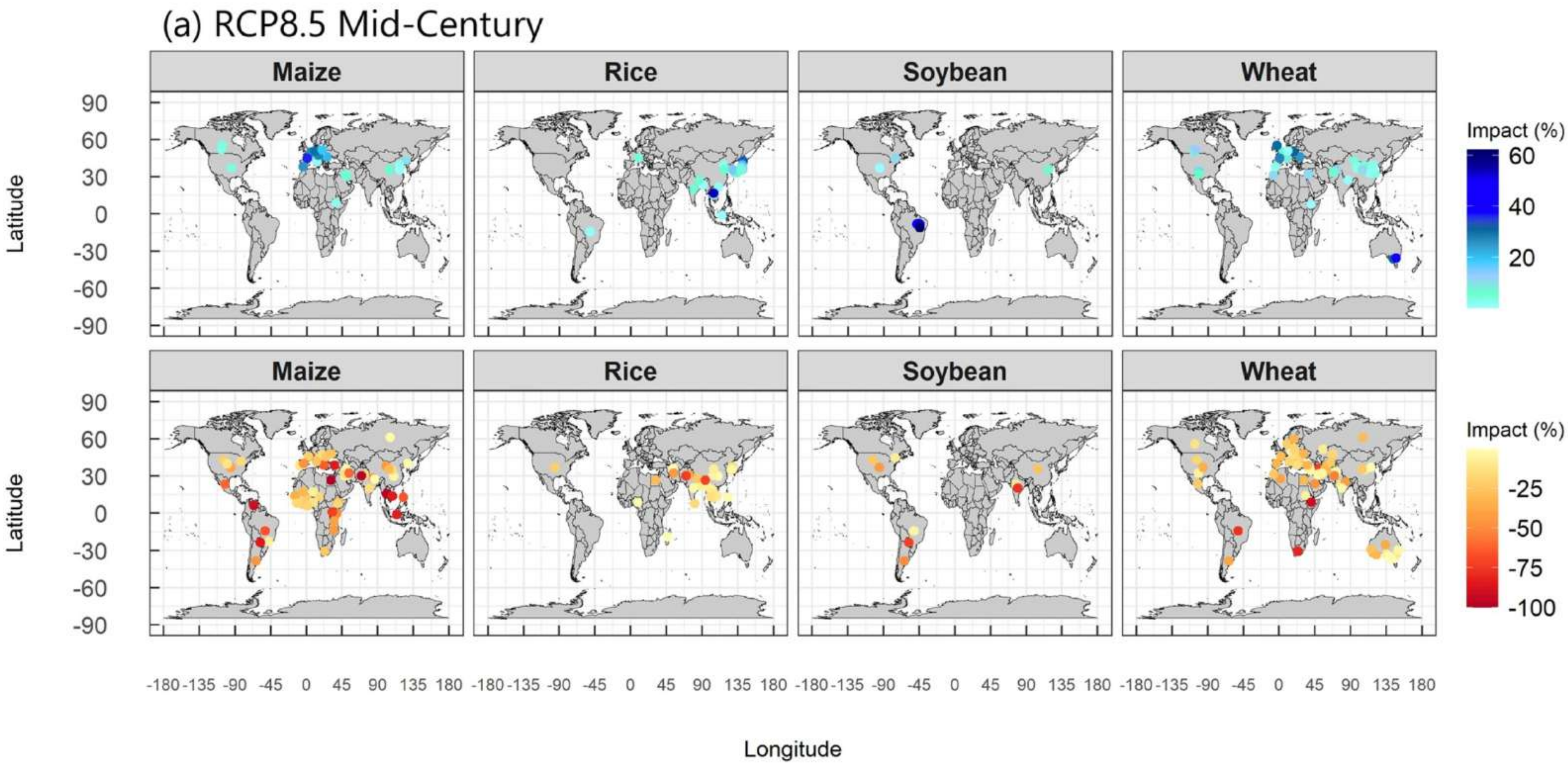

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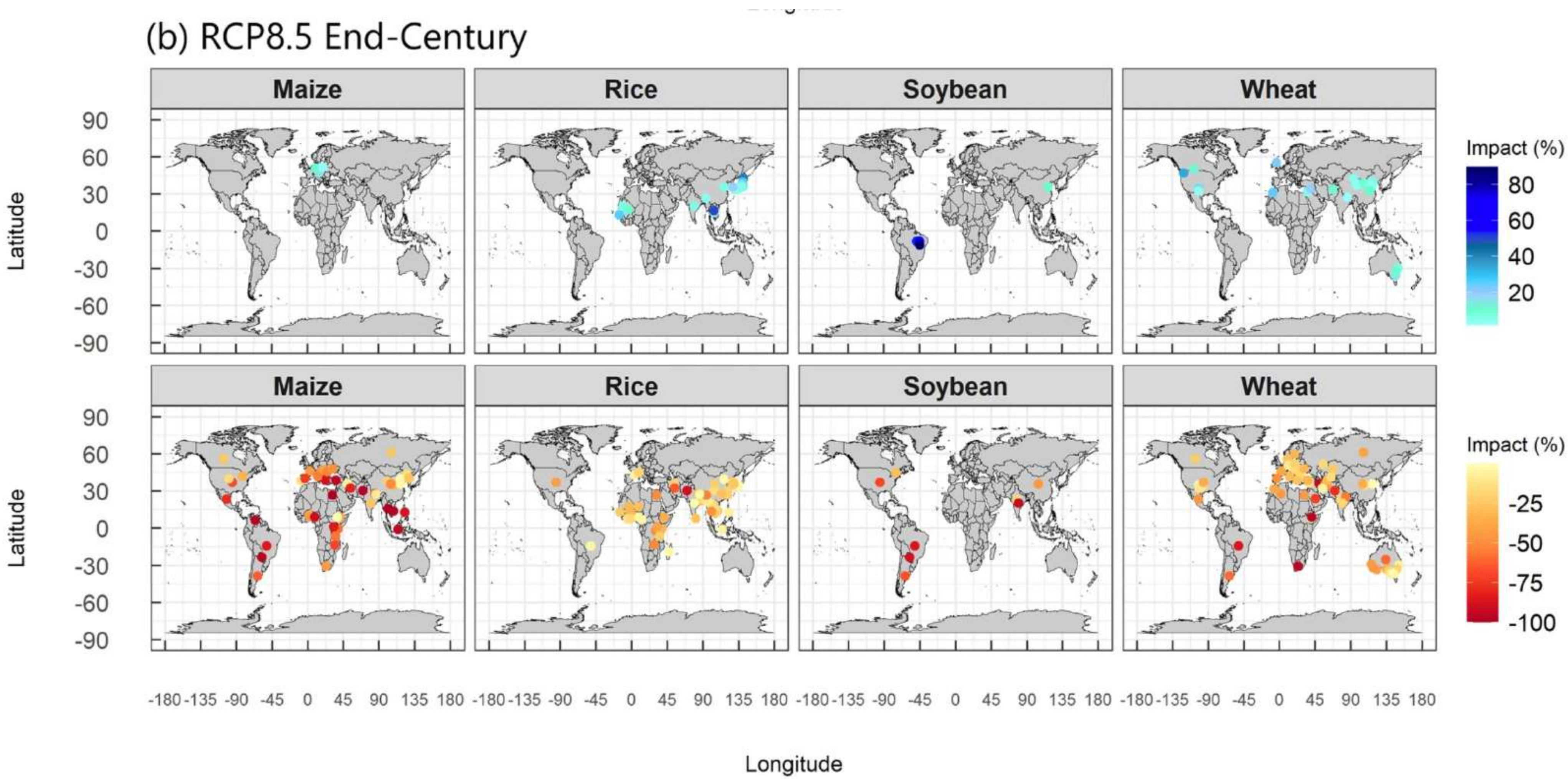

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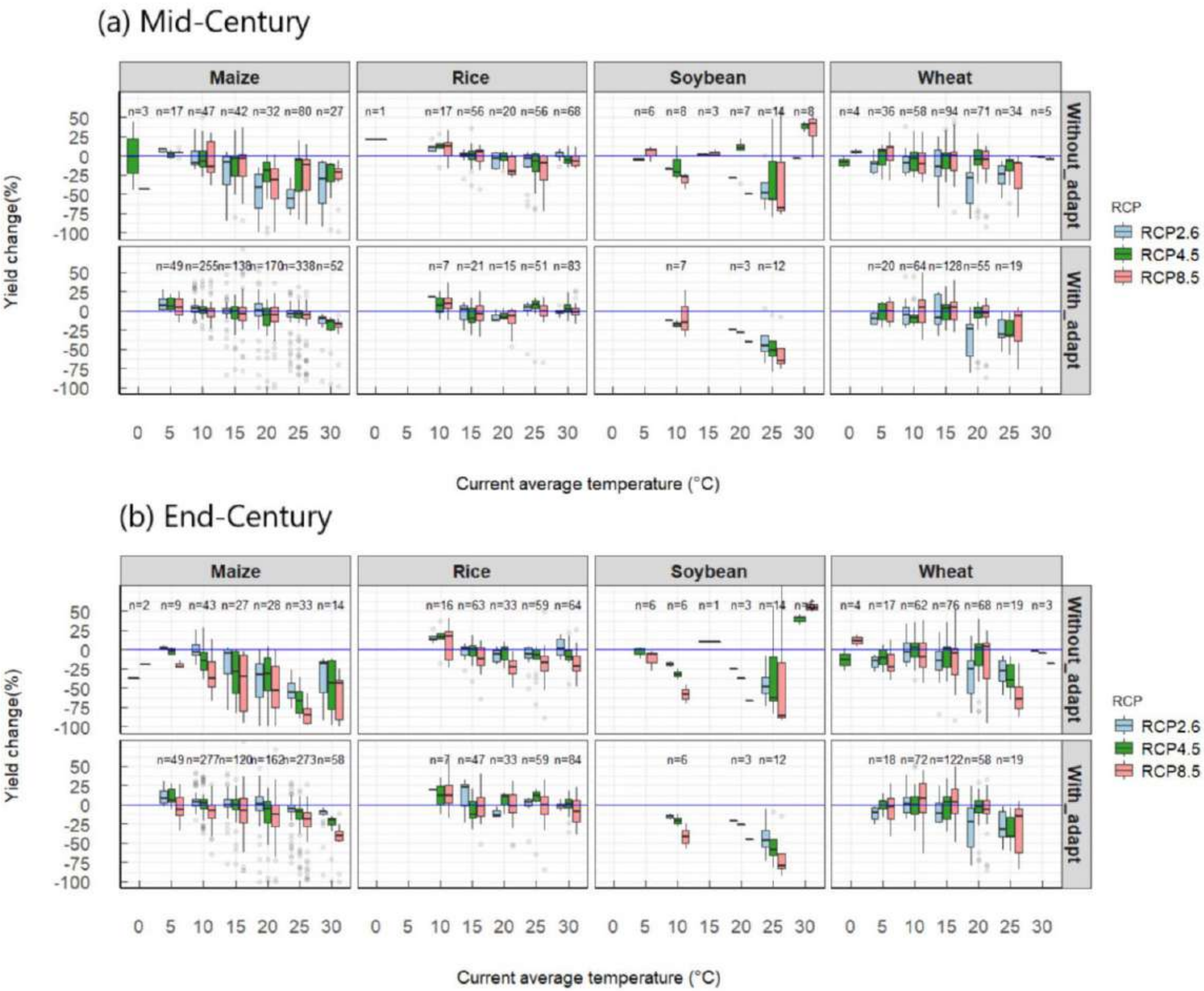
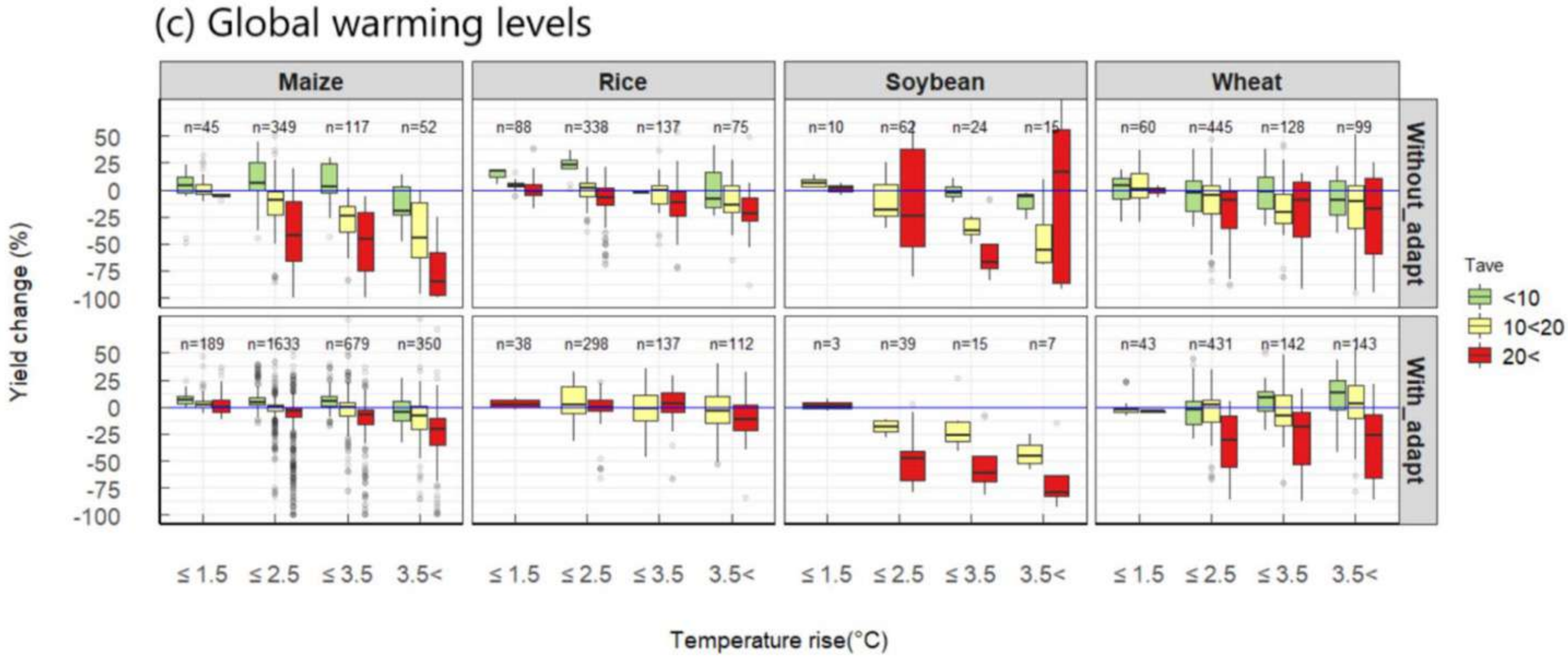

(a) Mid-Century
Maize
Rice
Soybean
Wheat
Without_adapt
With_adapt
Yield change(%)
50
25
0
-25
-50
-75
-100
n=3 n=17 n=47 n=42 n=32 n=80 n=27
n=1 n=17 n=56 n=20 n=56 n=68
n=6 n=8 n=3 n=7 n=14 n=8
n=4 n=36 n=58 n=94 n=71 n=34 n=5
n=49 n=255 n=138 n=170 n=338 n=52
n=7 n=21 n=15 n=51 n=83
n=7 n=3 n=12
n=20 n=64 n=128 n=55 n=19
0 5 10 15 20 25 30
Current average temperature (°C)
RCP
RCP2.6
RCP4.5
RCP8.5
(b) End-Century
Maize
Rice
Soybean
Wheat
Without_adapt
With_adapt
Yield change(%)
50
25
0
-25
-50
-75
-100
n=2 n=9 n=43 n=27 n=28 n=33 n=14
n=16 n=63 n=33 n=59 n=64
n=6 n=6 n=1 n=3 n=14 n=6
n=4 n=17 n=62 n=76 n=68 n=19 n=3
n=49 n=277 n=120 n=162 n=273 n=58
n=7 n=47 n=33 n=59 n=84
n=6 n=3 n=12
n=18 n=72 n=122 n=58 n=19
0 5 10 15 20 25 30
Current average temperature (°C)
RCP
RCP2.6
RCP4.5
RCP8.5



https://doi.org/10.1038/s41597-022-01150-7

The dataset can be downloaded from:

https://www.nature.com/articles/s41597-022-01150-7

Model testing

Model testing

Model No.	***Model Type***	***Predictors***	***Random Effect***
1	RF	Latitude + Longitude	-
2	GB	Latitude + Longitude	-
3	RF	$T_{avg} + P_{avg} + \Delta T + \Delta P + CO_2 + Adaptation$	-
4	GB	$T_{avg} + P_{avg} + \Delta T + \Delta P + CO_2 + Adaptation$	-
5	RF	Latitude + Longitude + $T_{avg} + P_{avg} + \Delta T + \Delta P + CO_2$ $+ Adaptation$	-
6	GB	Latitude + Longitude + $T_{avg} + P_{avg} + \Delta T + \Delta P + CO_2$ $+ Adaptation$	-
7	LM	$T_{avg} + P_{avg} + \Delta T + \Delta P + CO_2 + Adaptation$	(1|Study reference)
8	LM	$T_{avg} * P_{avg} * \Delta T * \Delta P * CO_2 * Adaptation$	(1|Study reference)
9	LM	1	$Matern(1 \vert Longitude + Latitude)$
10	LM	$T_{avg} + P_{avg} + \Delta T + \Delta P + CO_2 + Adaptation$	$Matern(1 \vert Longitude + Latitude)$

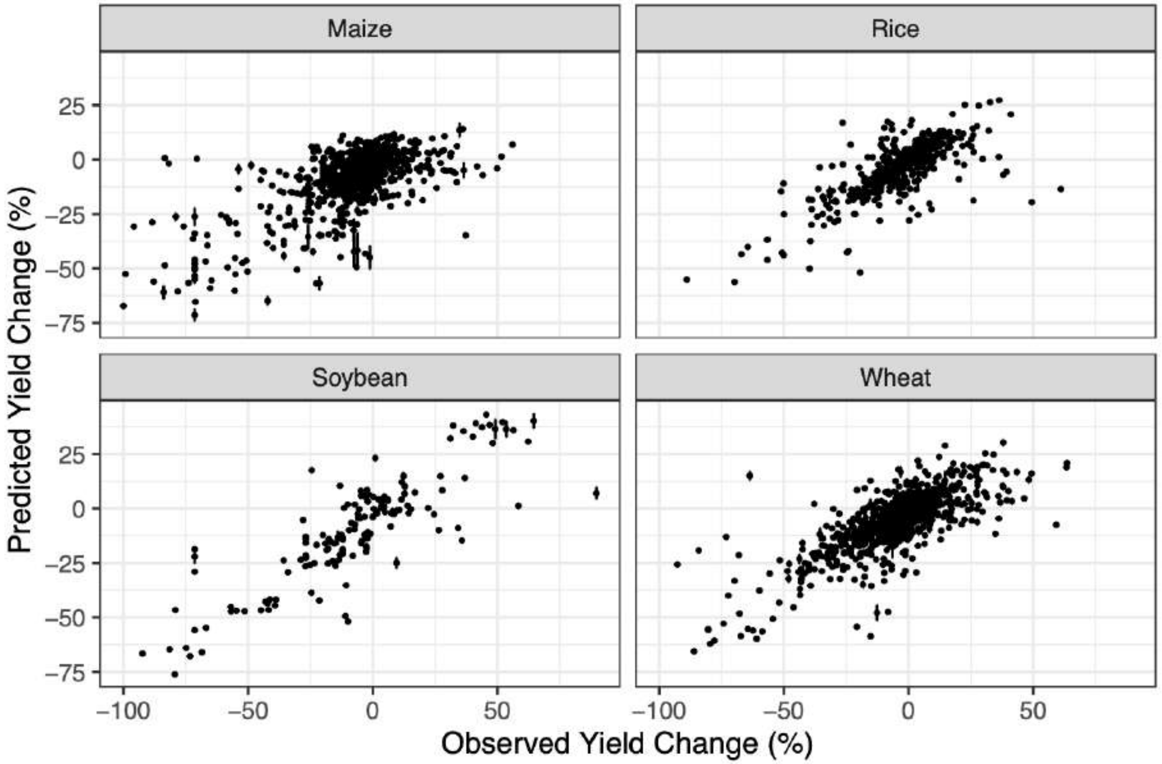
RF=random forest, GB=gradient boosting, LM=linear model

Model testing

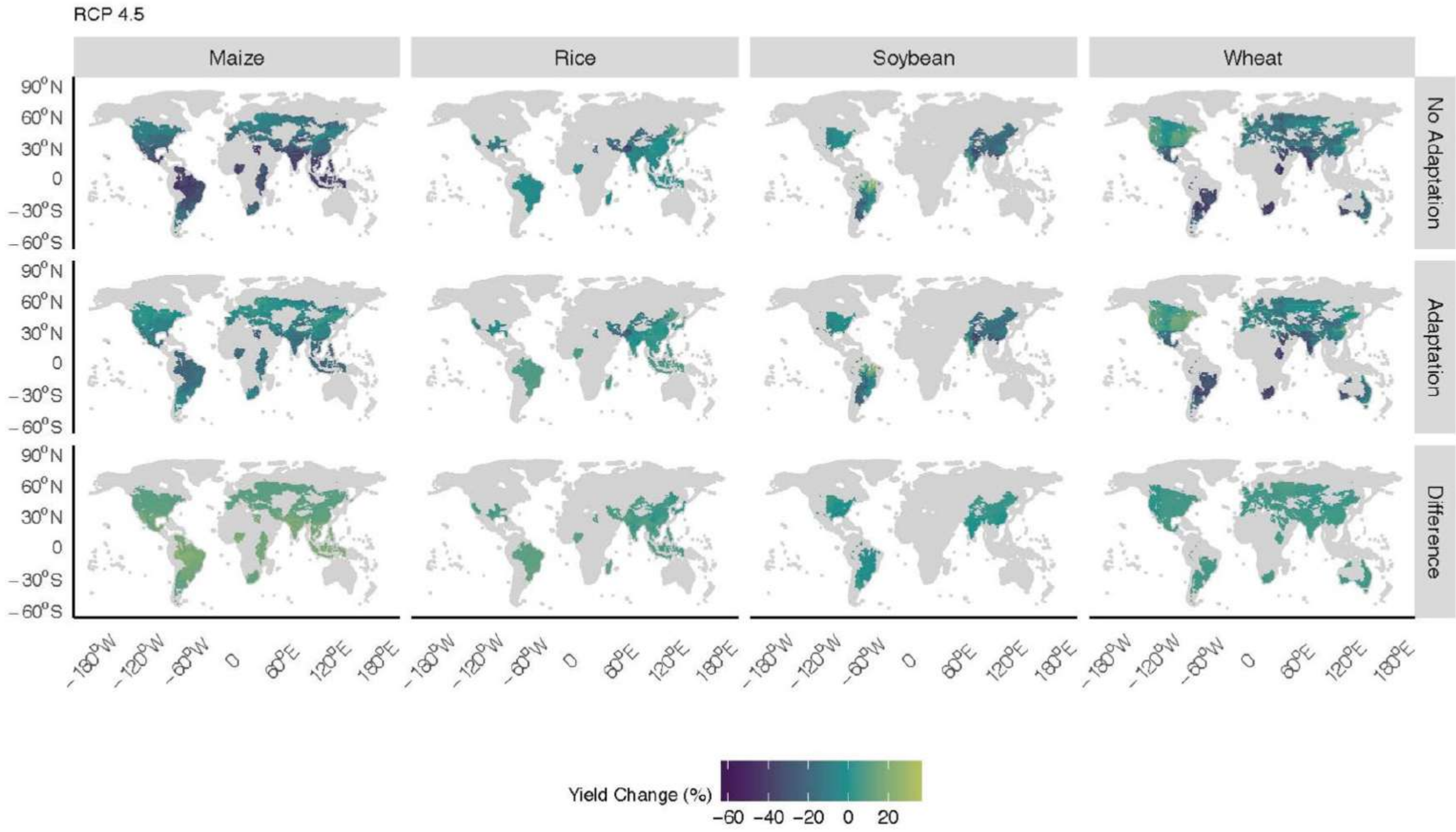
- For all models, we split the dataset by location into a training (75% of data) and a testing dataset (25% of data).
- Two types of data splitting procedures were implemented.
  - ➢ First, the data split was done such that test locations were the same as those of the training dataset.
  - ➢ Second, the data split was done such that all of the yield predictions in the testing dataset were from different locations than those of the training dataset.
- Repeated 10 times
- RMSE and R^2 computed from the test datasets at each iteration

Model testing

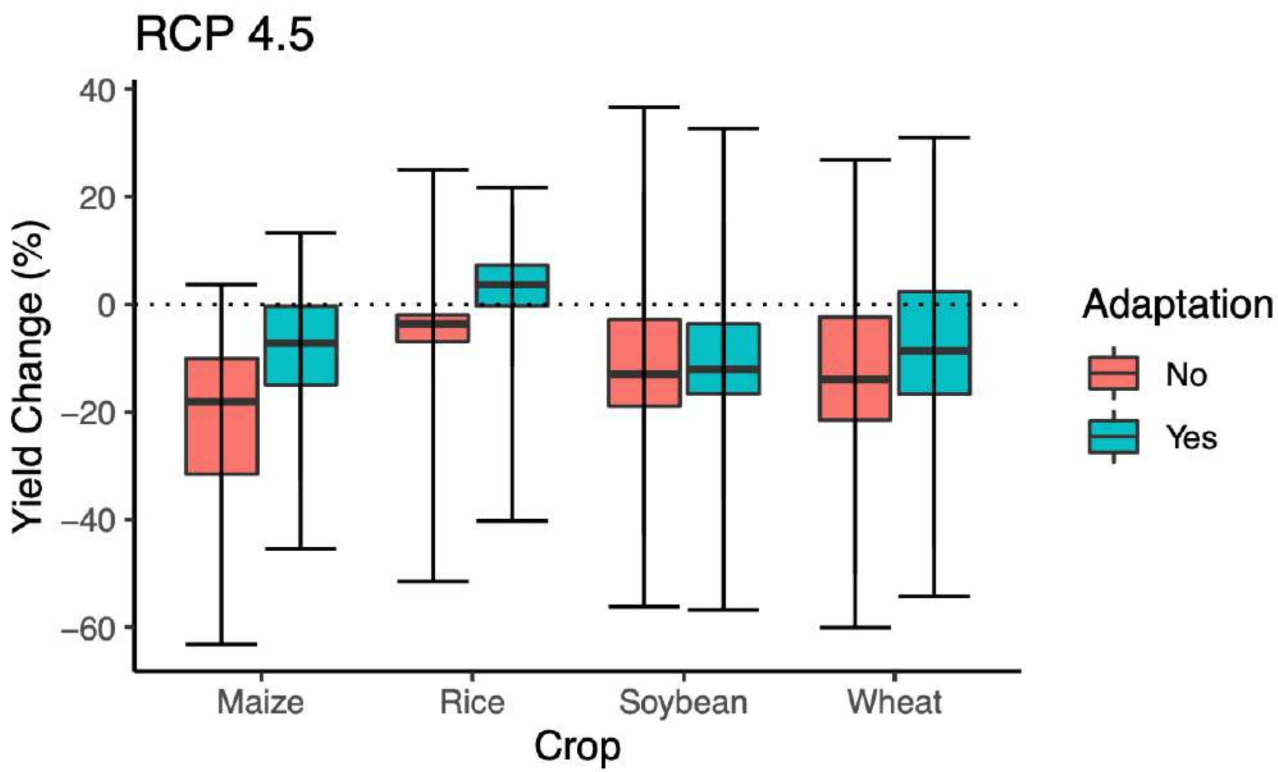
Crop	Selected model	RMSE
Maize	4	17.5 +- 0.8
Rice	5	14.8 +-1.1
Soybean	5	28.2 +-3.8
Wheat	6	19.0 +-1.1



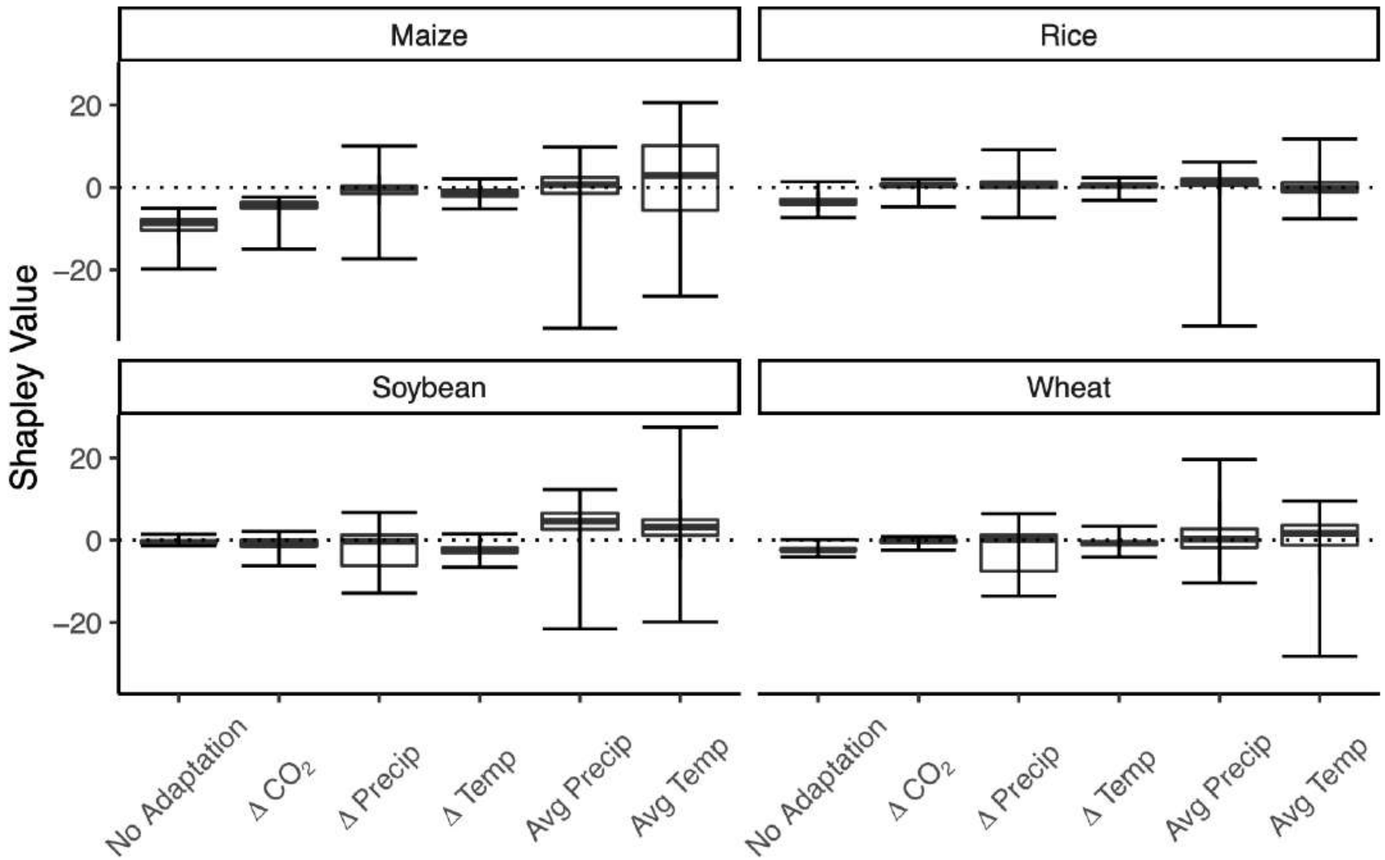
Effect of adaptation


RCP 4.5
Maize
Rice
Soybean
Wheat
No Adaptation
Adaptation
Difference
90°N
60°N
30°N
0
−30°S
−60°S
−180°W
−120°W
−60°W
0
60°E
120°E
180°E
Yield Change (%)
−60 −40 −20 0 20

Yield changes with and without adaptation



Contribution of different factors to the predicted yield changes



Summary

- Without adaptation under RCP4.5, crops are expected to experience average global yield losses of 6–21%.
- Adaptation alleviates this average loss by 1–13%.
- Maize was most responsive to adaptive practices with a mean yield loss of
    - -21 % [range across locations: -63%, +3.7%] without adaptation
    - -7.5% [range: -46%, +13%] with adaptation.
- For maize and rice, irrigation method and cultivar choice were the adaptation types most able to prevent large yield losses, respectively.
- When adaptation practices are applied, some areas may experience yield gains, especially at northern high latitudes.