AgroParisTech Talents d'une planète soutenable | Unité mixte de recherche Agronomie | Université Paris-Saclay

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Europe's soybean self-sufficiency under climate-change: insights from data-driven yield projections using machine-learning

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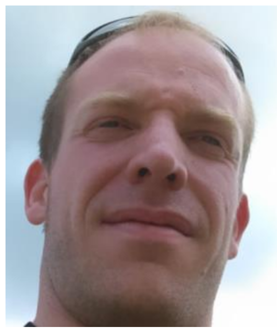

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LEGVALUE

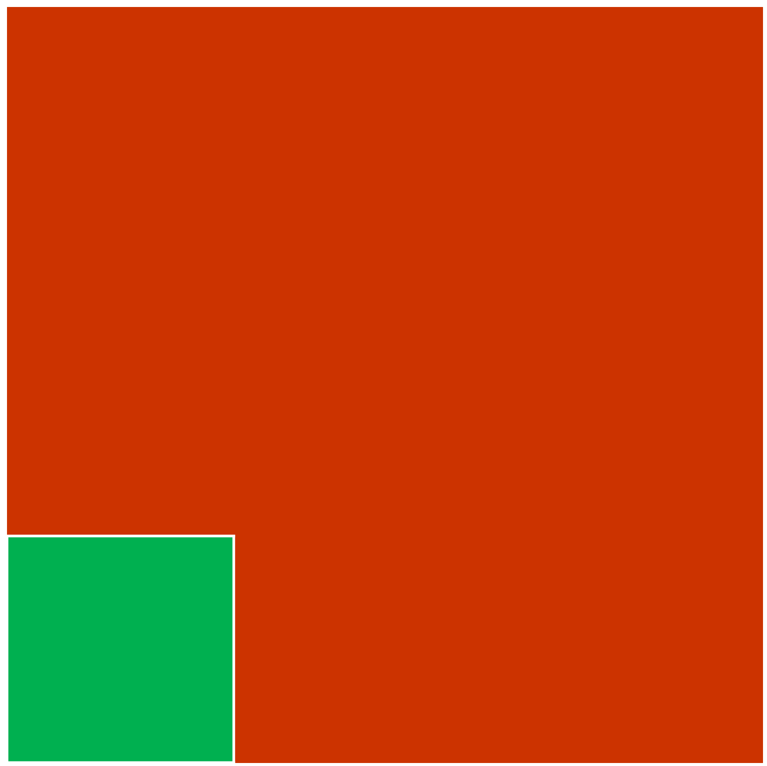
01

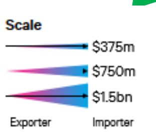
Europe's dependence on soybean imports

European soybean domestic supply

Imports (90%)

Production (10%)



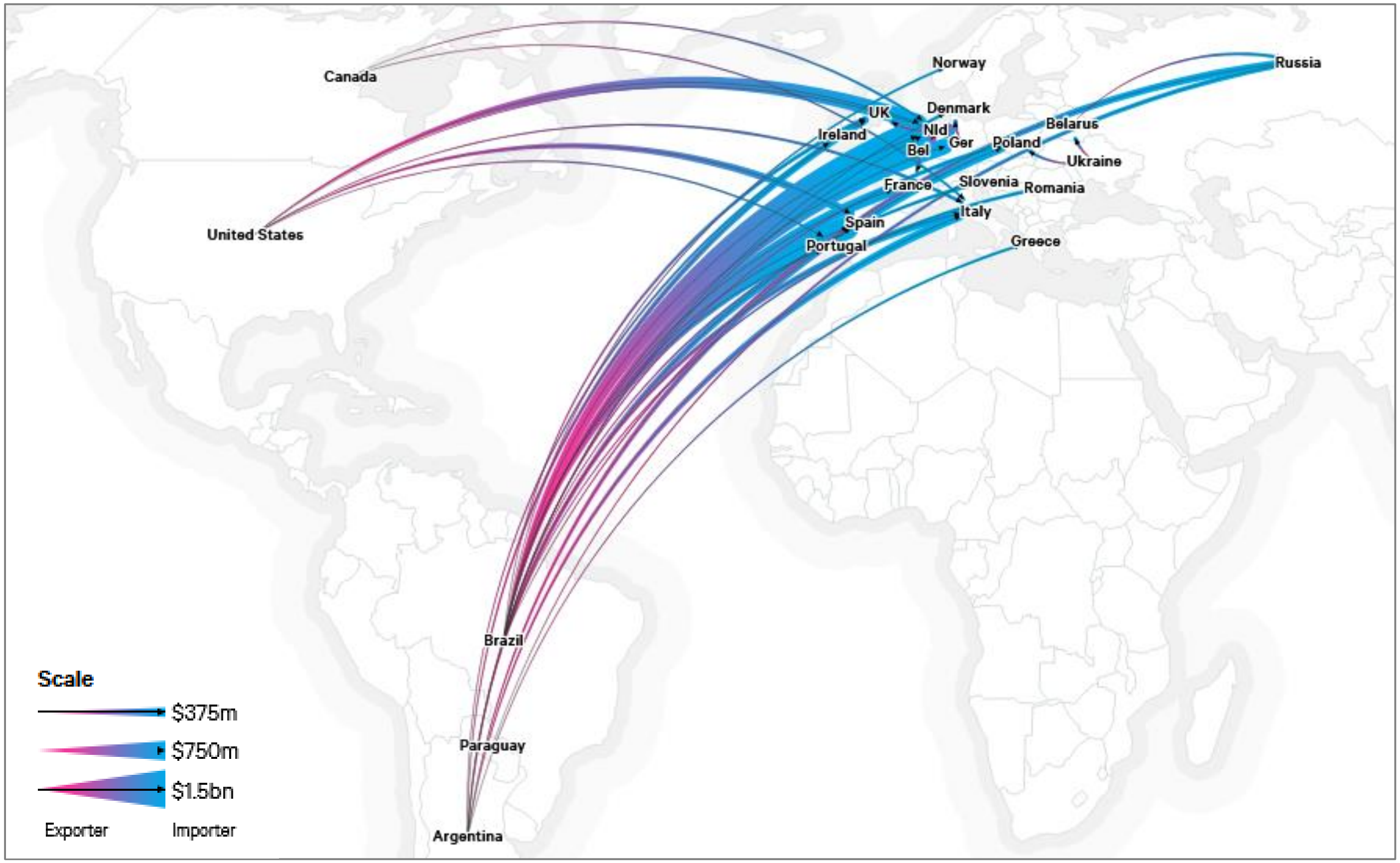


Soybean area < 2% of European cropland in 2016

Source : FAOSTAT (average 2009-2013)

Soybean is mainly imported to Europe from south America

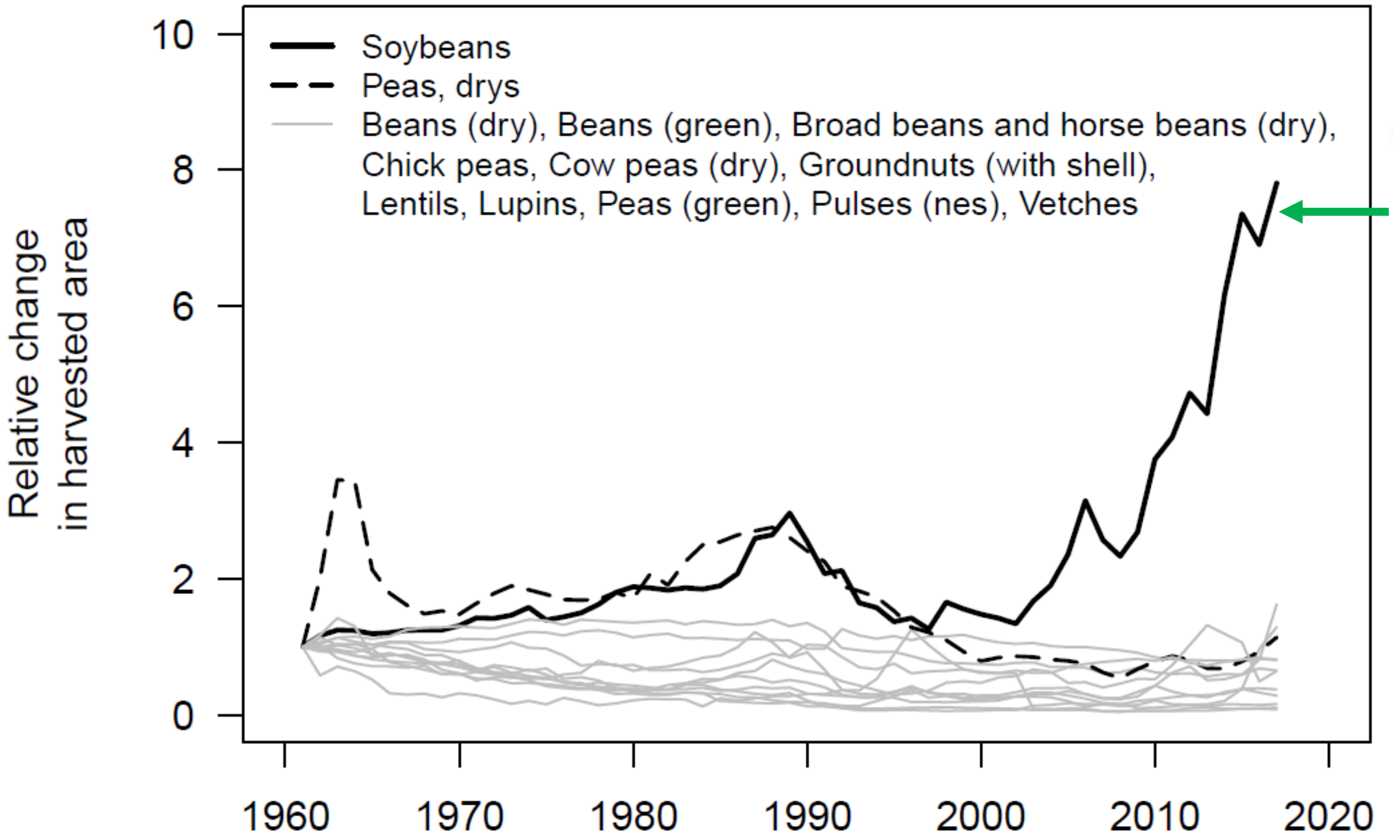
Year 2020



Source : https://resourcetrade.earth

The Amazon rainforest meets soybean fields in Mato Grosso, Brazil. Paralxis/Shutterstock

Historical trends in legumes harvested area in Europe



Source : FAOSTAT (2018)

The question(s)

Where can we grow soybean in Europe and will suitable areas be modified by climate change?

- What are the climatic drivers of projected shift in suitabe areas?
- How much area would be required to reach 50% and 100% self-sufficiency in soybean given projected yields?
- How much nitrogen fertilizer could be saved from soybean expansion?

02

Methods and data sources

Data sources

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2014) 23, 346–357

RESEARCH PAPER

Historical changes in global yields: major cereal and legume crops from 1982 to 2006

Toshichika Iizumi[1*], Masayuki Yokozawa[1], Gen Sakurai[1], Maria Isabel Travasso[2], Vladimir Romanenkov[3], Pascal Oettli[4], Terry Newby[5], Yasushi Ishigooka[1] and Jun Furuya[6]

Global Data set of Historical Yields of major crops version 1.1 (GDHY1.1)

- Yields of maize, <u>soybean</u>, rice, wheat
- From 1981 to 2011
- 1.125-degree-grid-cell
- Constant harvested area of circa 2000

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD020130

Key Points:

- The study presents a creation of forcing data set for global crop modeling
- The data set offers daily weather variables over global land for 1961–2010
- The data offer accurate estimates of daily weather as the inputs for crop

A meteorological forcing data set for global crop modeling: Development, evaluation, and intercomparison

Toshichika Iizumi[1], Masashi Okada[1], and Masayuki Yokozawza[1]

[1]Agro-Meteorology Division, National Institute for Agro-Environmental Sciences, Tsukuba, Japan

GRASP meteorological Forcing Data for global crop modeling

- Monthly climate variables (Tmin, Tmax, rain, solar radiation, VP)
- From 1961 to 2010
- 1.125-degree-grid-cell

Agricultural Systems 127 (2014) 53–60

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

ELSEVIER

Research Paper

Generating global crop distribution maps: From census to grid

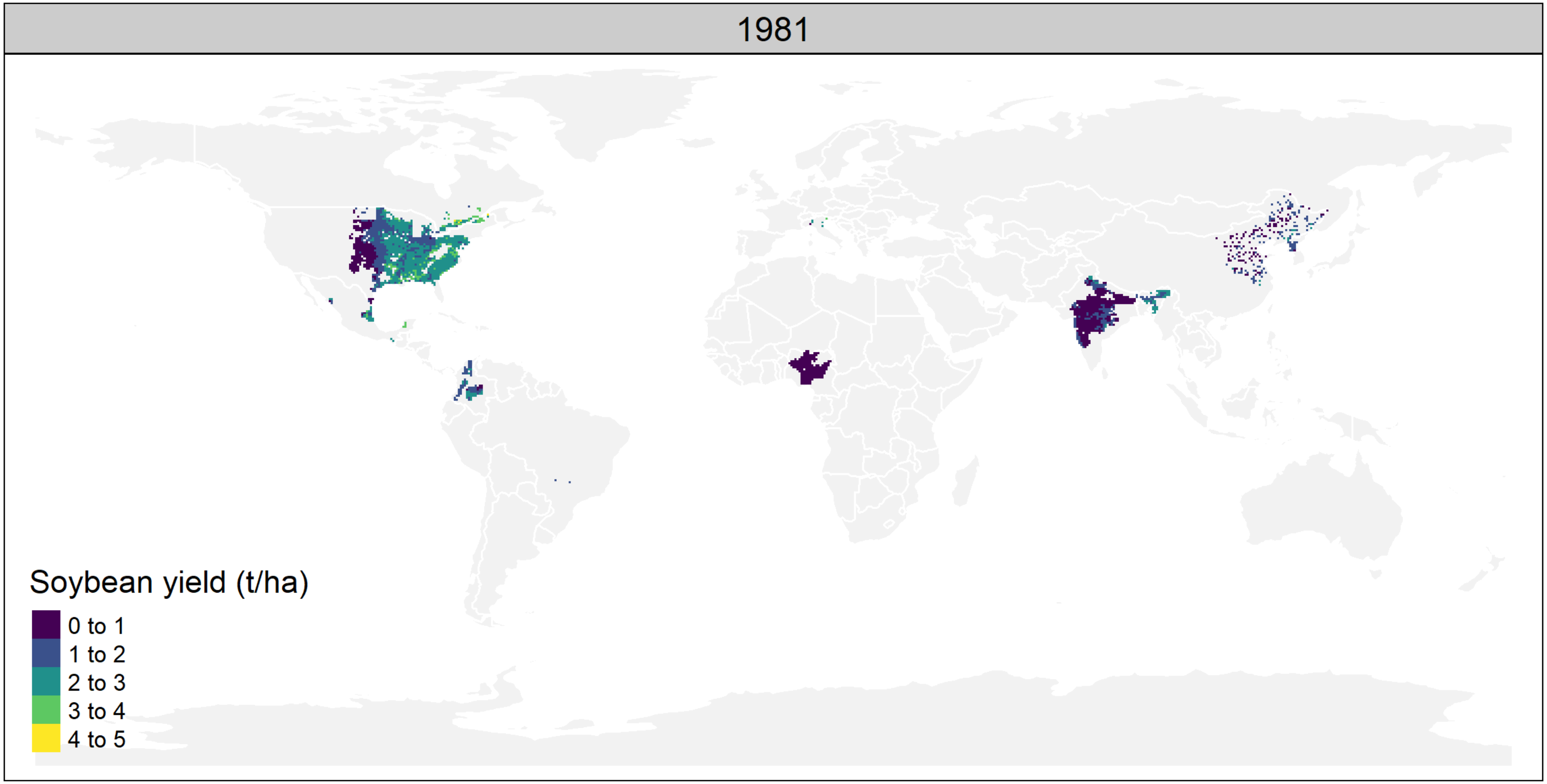
Liangzhi You[a,b,*], Stanley Wood[c], Ulrike Wood-Sichra[b], Wenbin Wu[d]

[a]College of Economics and Management, Huazhong Agricultural University, Wuhan, Hubei 430070, China
[b]International Food Policy Research Institute, 2033 K Street, NW, Washington, DC 20006, USA
[c]Bill & Melinda Gates Foundation, 500 Fifth Avenue North, Seattle, WA 98109, USA
[d]Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China

Spatial Allocation Model (SPAM)

- Maps of rainfed/irrigated systems
- Around the year 2005
- 5 arc-minute (~0.08 degree) grid cell

How do Big Data look like for Soybean?



Toshichika, I., & Toru, S. (2020). The global dataset of historical yields for major crops 1981–2016. *Scientific Data*, *7*(1).

Model description

First month of the soybean growing season

Soybean yield ~	Tmin.1 + Tmin.2 + … + Tmin.7
(trend removed)	+ Tmax.1 + Tmax.2 + … + Tmax.7
	+ Rain.1 + Rain.2 + … + Rain.7
	+ Solar.1 + Solar.2 + … + Solar.7
	+ Vp.1 + Vp.2 + … + Vp.7
	+ irrigated fraction

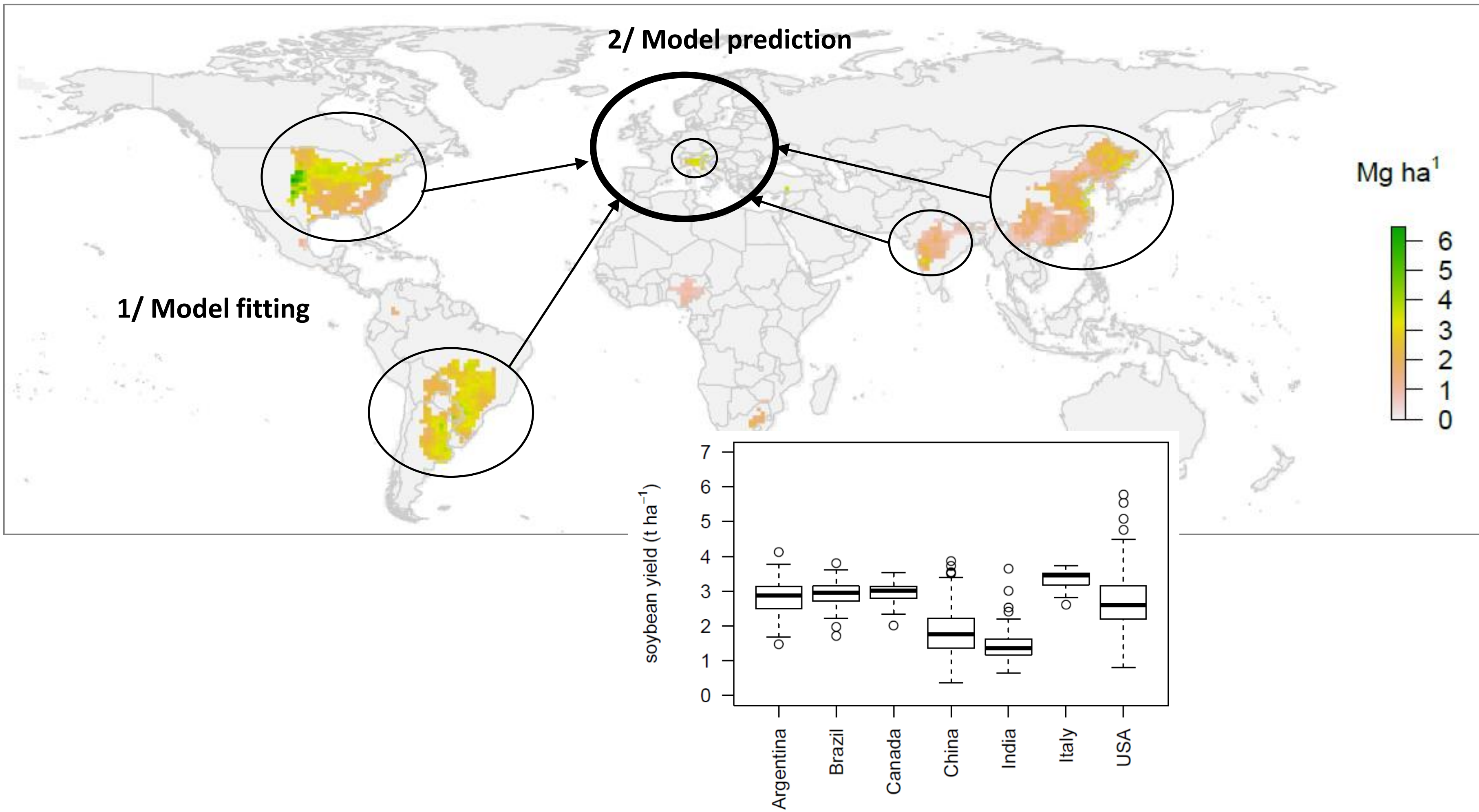
TOTAL = 36 predictors (35 climatic variables + irrigated fraction in a pixel)

Random Forest (regression)
Artificial Neural Networks (ANN)
Generalized Linear Model (GLM)
Generalized Additive Model (GAM)

Omitted factors
Photoperiod (daylength)
Soil type
CO_2

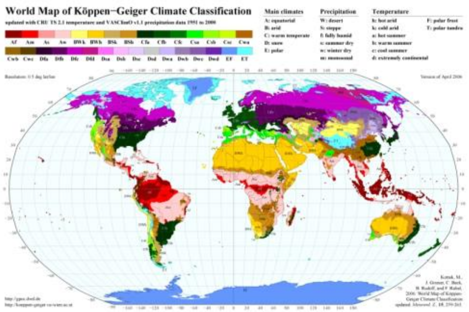
Guilpart, N., Iizumi, T., & Makowski, D. (2022). Data-driven projections suggest large opportunities to improve Europe's soybean self-sufficiency under climate change. *Nature Food*, *3*(4), 255-265.

Map of soybean yield in 2010



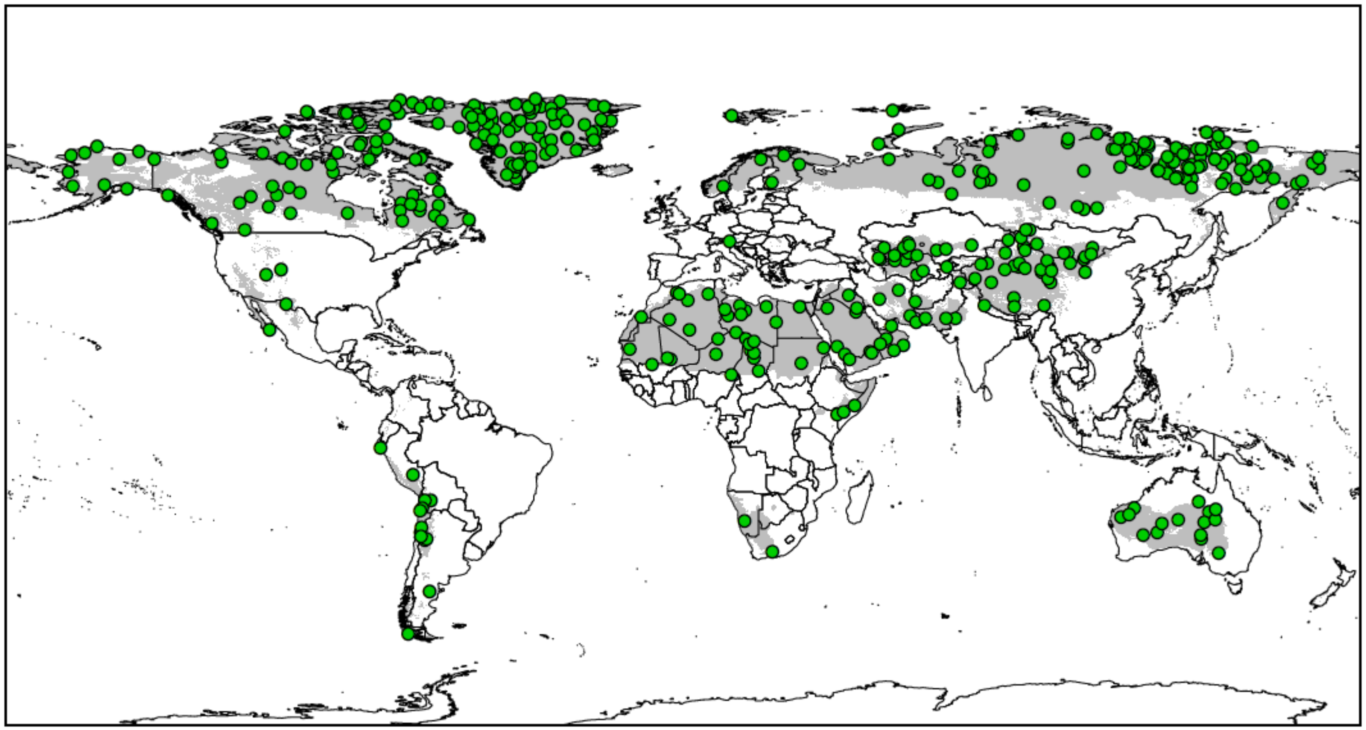
Guilpart, N., Iizumi, T., & Makowski, D. (2022). Data-driven projections suggest large opportunities to improve Europe's soybean self-sufficiency under climate change. *Nature Food*, *3*(4), 255-265.

Koppen-Geiger Climate zones



Adding « true absences » (yield = 0)

<u>Map of true absences added to the training dataset</u>

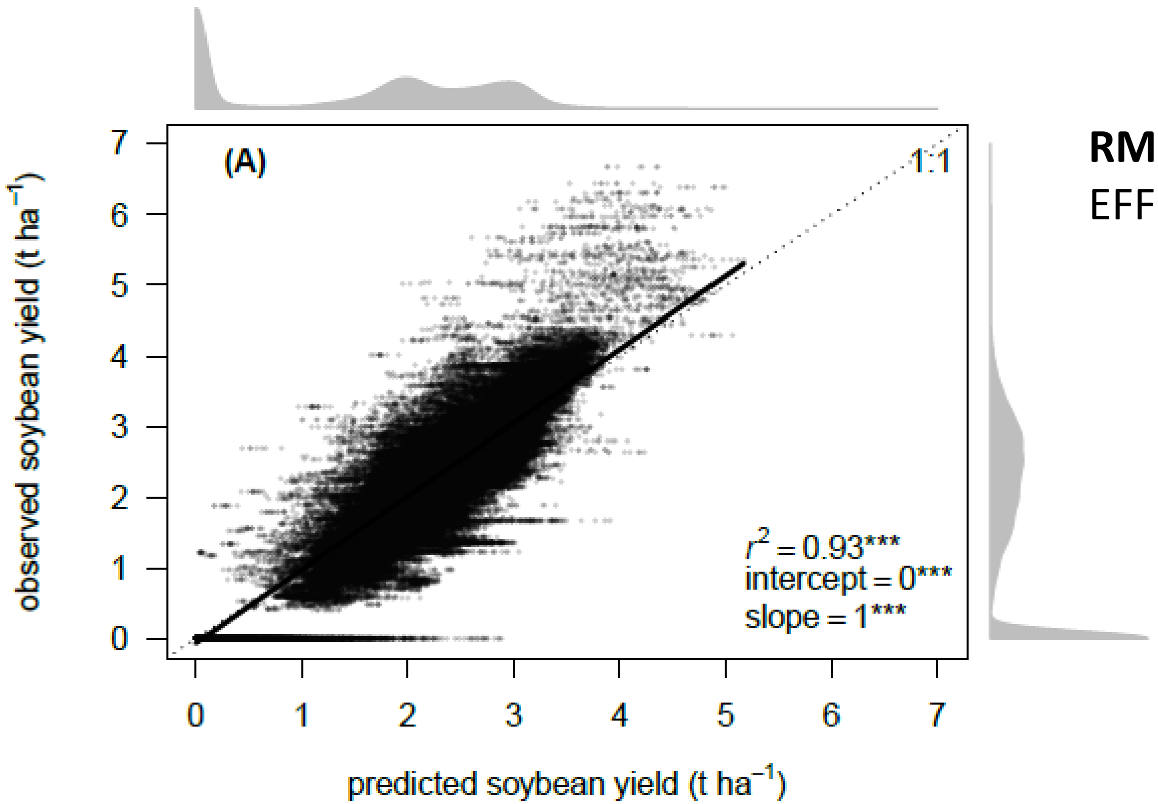


True absences represent 20% of the final dataset
(Final dataset : ~ 30 000 observations)

http://koeppen-geiger.vu-wien.ac.at/present.htm

Model evaluation

1/ With a classical bootstrap approach with 25 resamplings



RMSEP = 0.35 t ha^{-1}

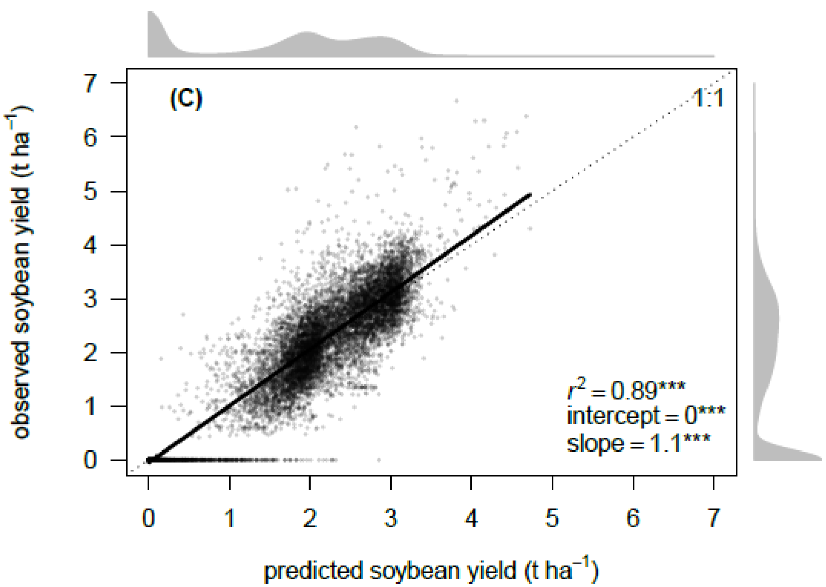
EFF = 0.93

Guilpart, N., Iizumi, T., & Makowski, D. (2022). Data-driven projections suggest large opportunities to improve Europe's soybean self-sufficiency under climate change. *Nature Food*, *3*(4), 255-265.

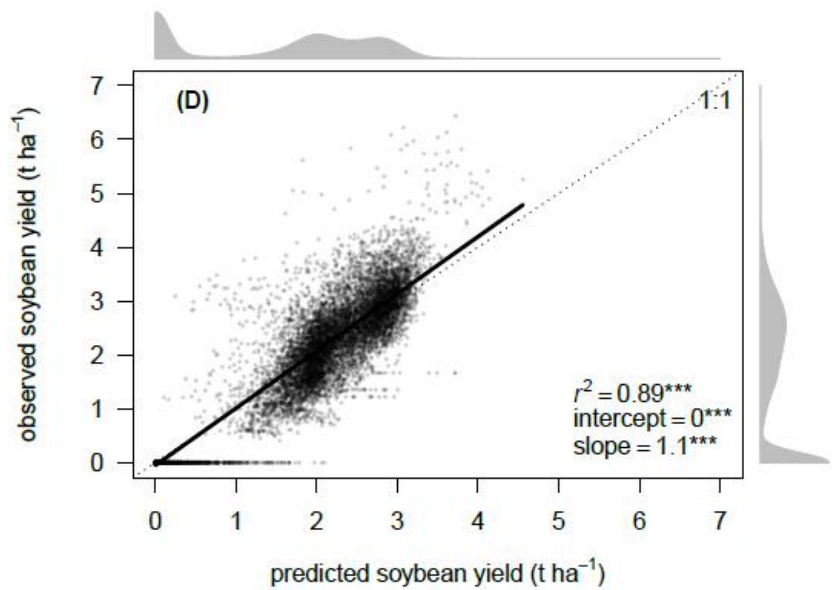
Model evaluation

2/ Transferability in time

Training period : 1981-1995
Predicted period : 1996-2010



Training period : 1996-2010
Predicted period : 1981-1995

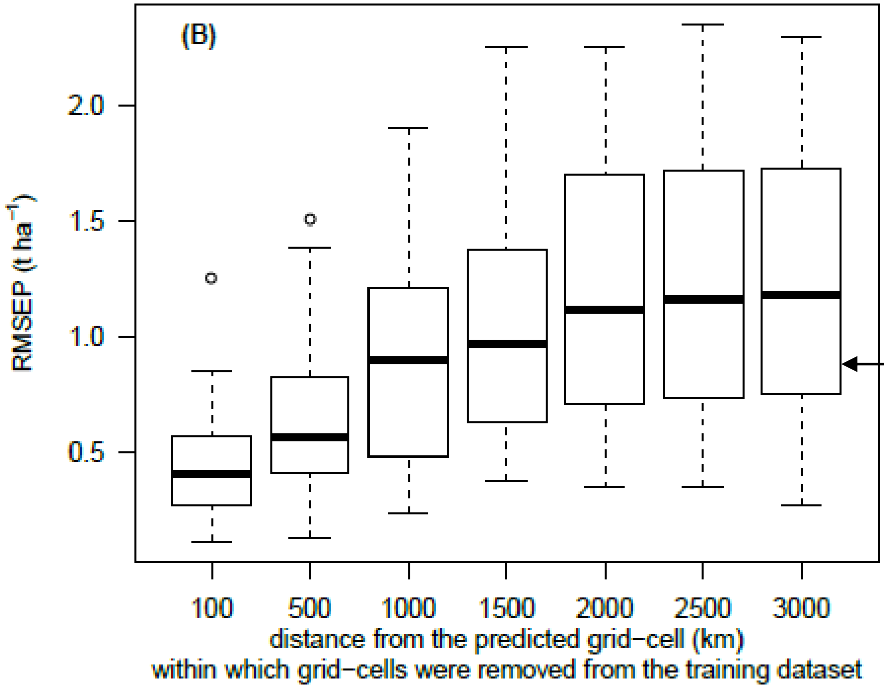


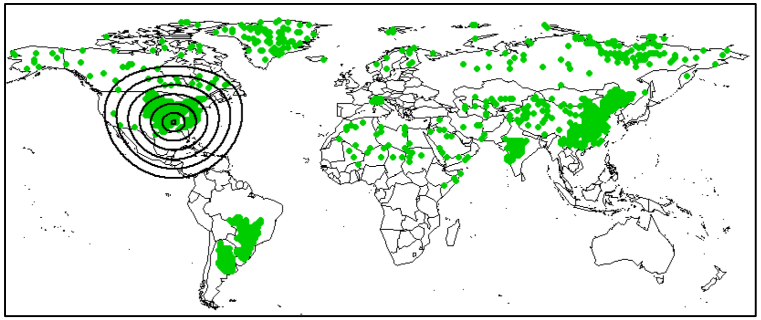
RMSEP = 0.45 t ha^{-1}
EFF = 0.88

Guilpart, N., Iizumi, T., & Makowski, D. (2022). Data-driven projections suggest large opportunities to improve Europe's soybean self-sufficiency under climate change. *Nature Food*, *3*(4), 255-265.

Model evaluation

3/ Transferability in space



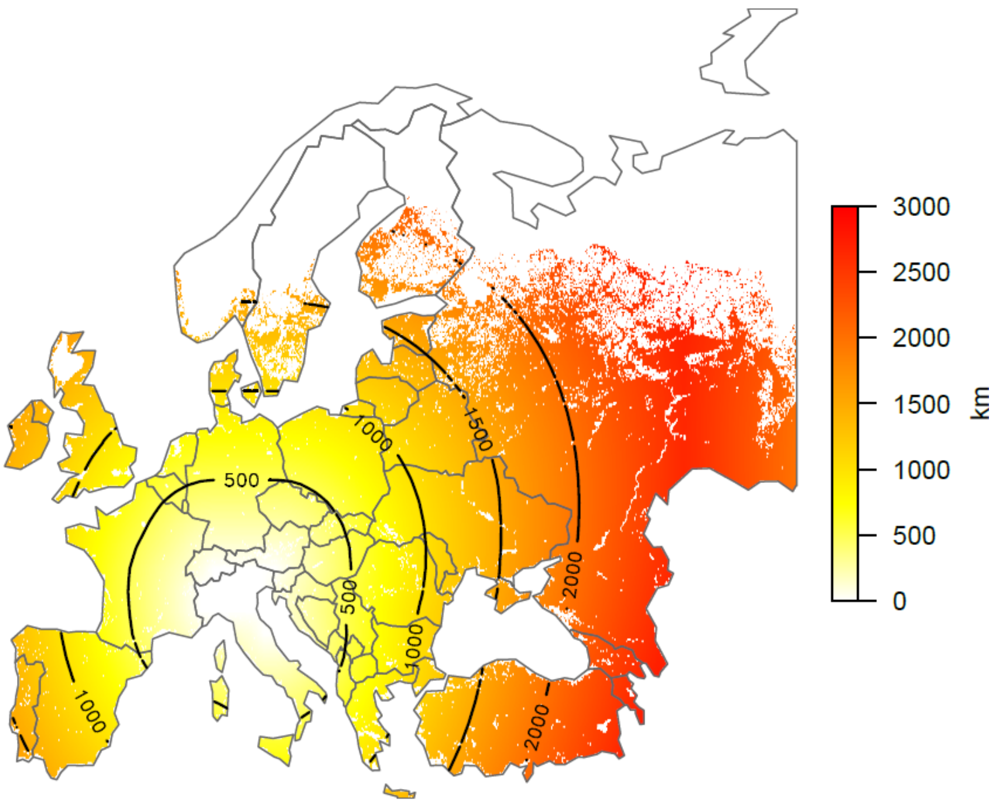


The boxplot represent 70 RMSEP values (10 grid-cells * 7 countries)

Increasing spatial distance between training and test datasets

Model evaluation

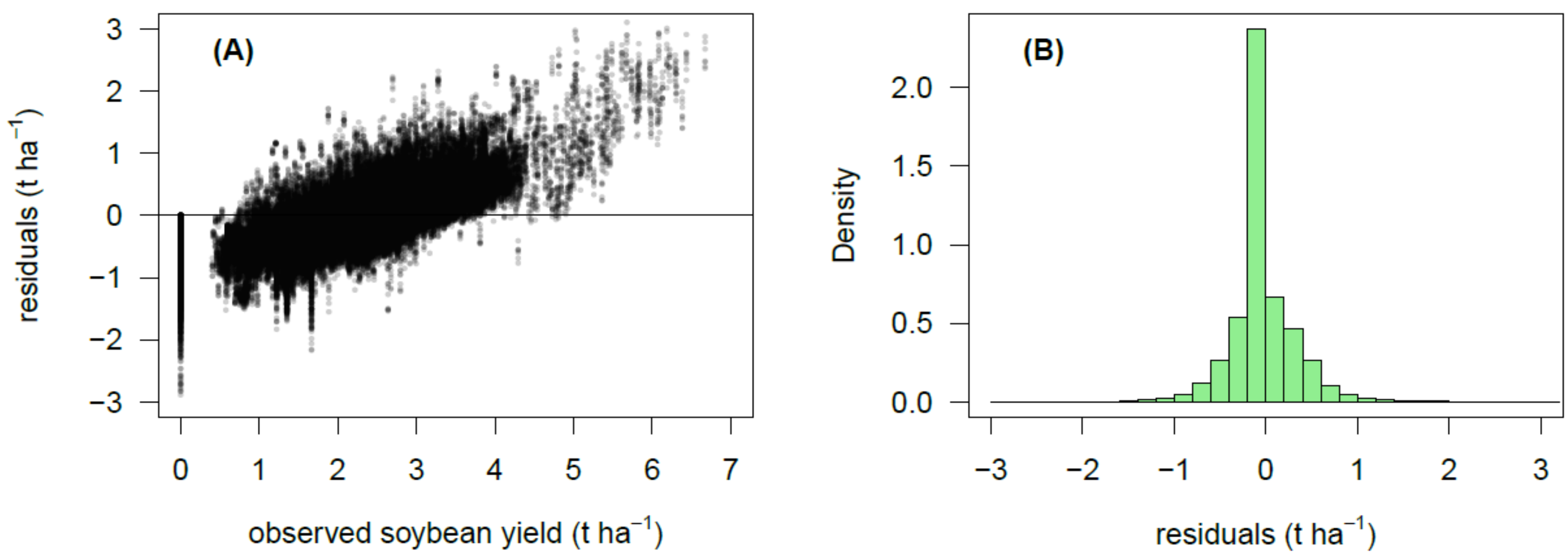
3/ Transferability in space



Distance to the nearest grid-cell with soybean in the training dataset

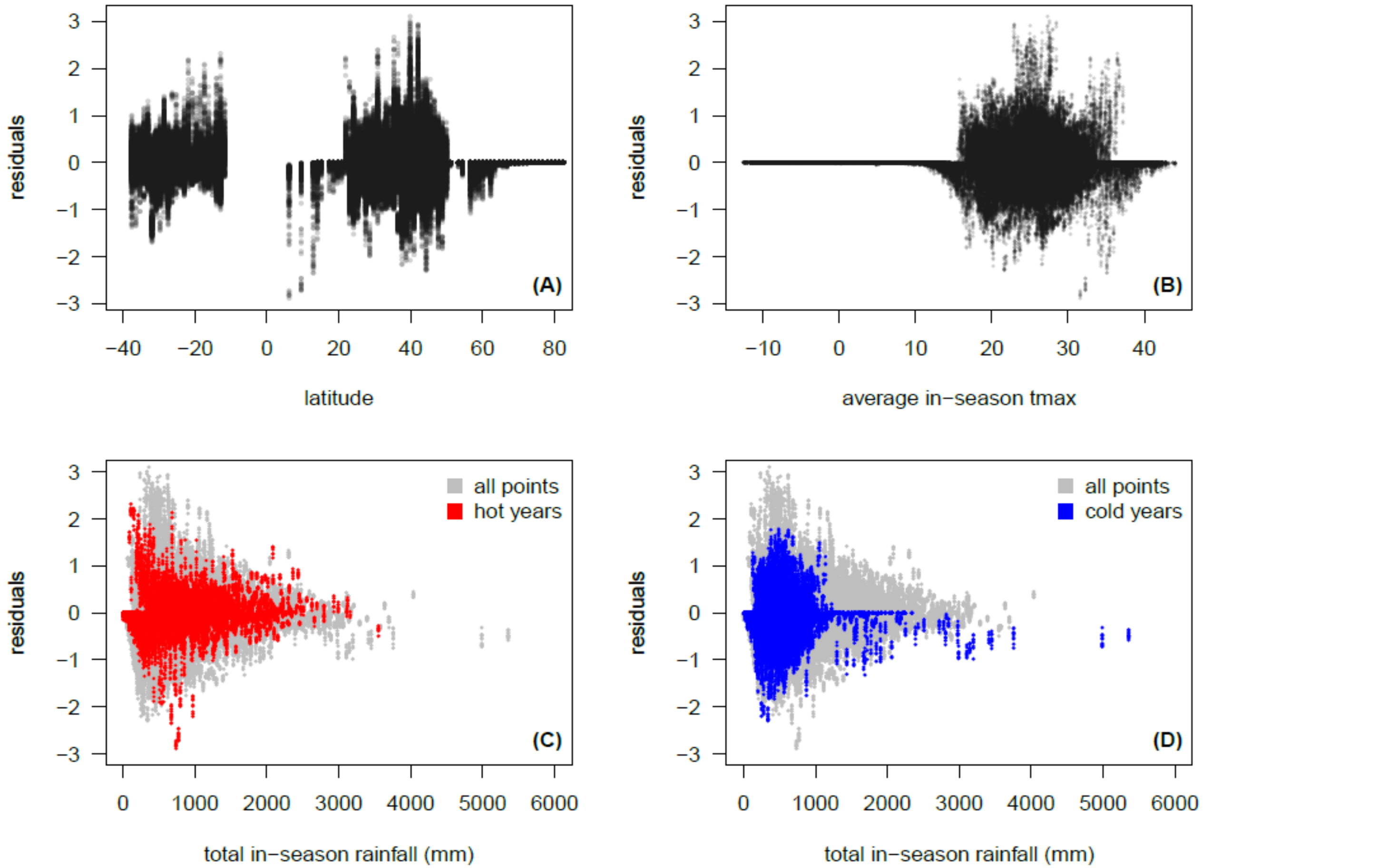
Model evaluation

4/ Model residuals



Model evaluation

4/ Model residuals



Climate scenarios considered for projections

8 Global Circulation Models

- GFDL-ESM2M
- HadGEM2-ES
- IPSL-CM5A-LR
- MIROC5
- MIROC-ESM
- MIROC-ESM-CHEM
- MRI-CGCM3
- NorESM1-M

X

2 RCPs

- Rcp45
- Rcp85

X

3 time periods

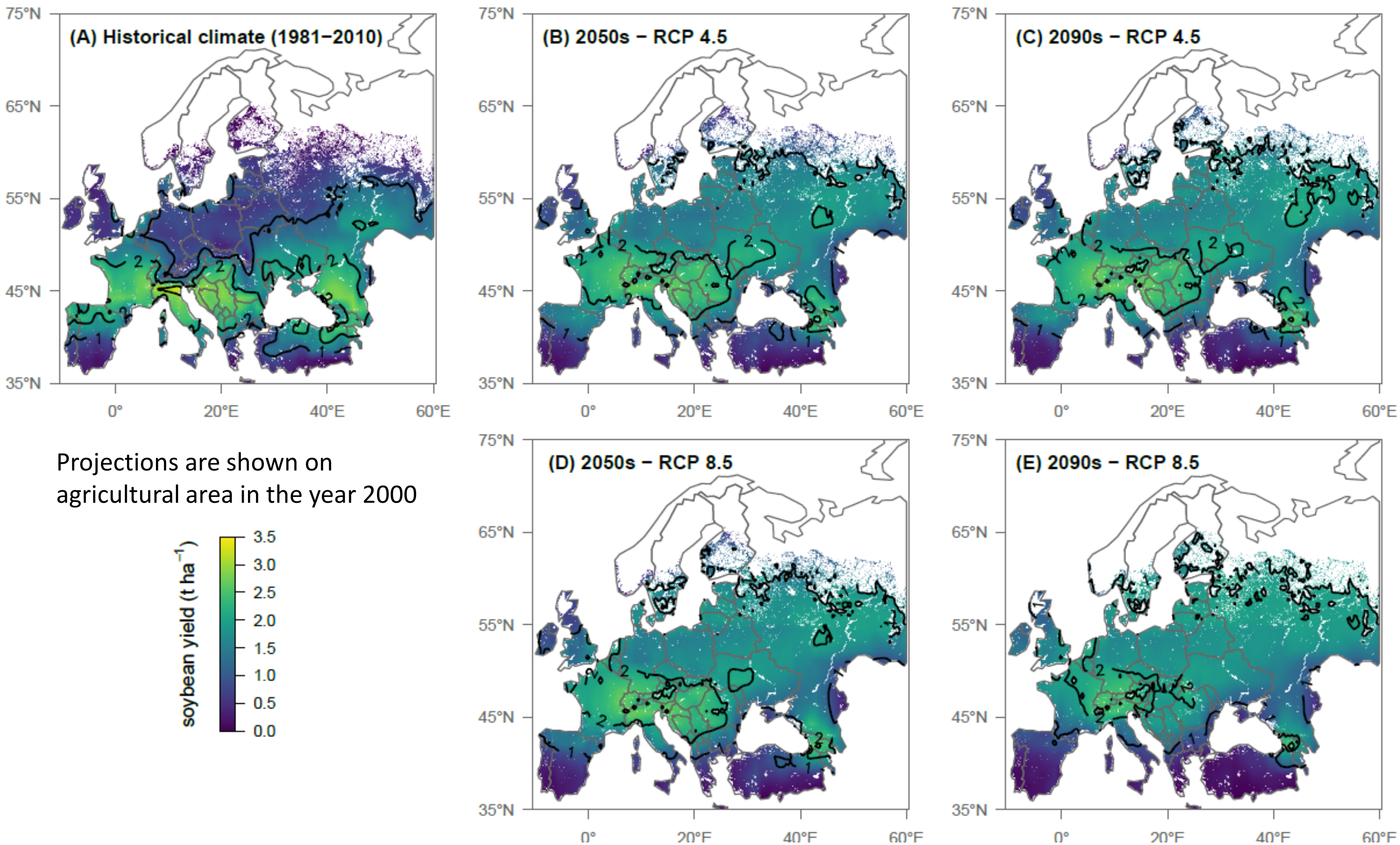
- 1981-2010 (historical)
- 2050-2059
- 2090-2099

→ Median predicted soybean yield over the 8 models
→ Soybean growing season : April to October

03

Results

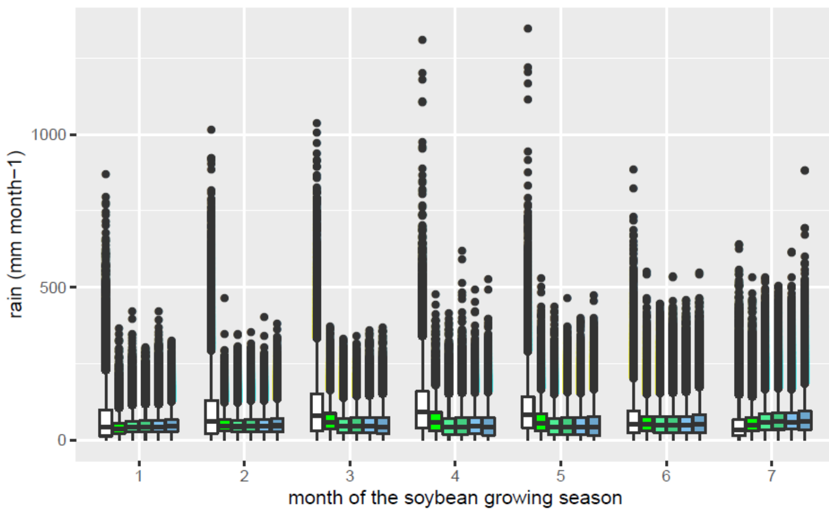
Projections in Europe : high suitability and shift towards the north-east

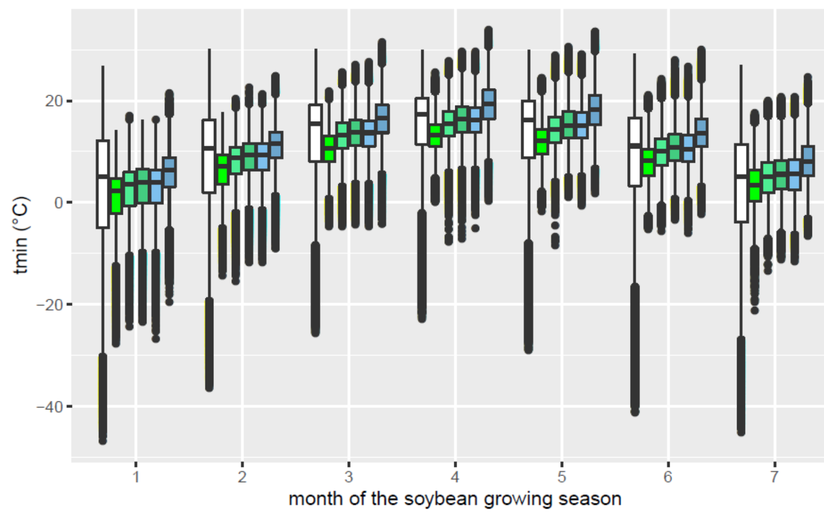


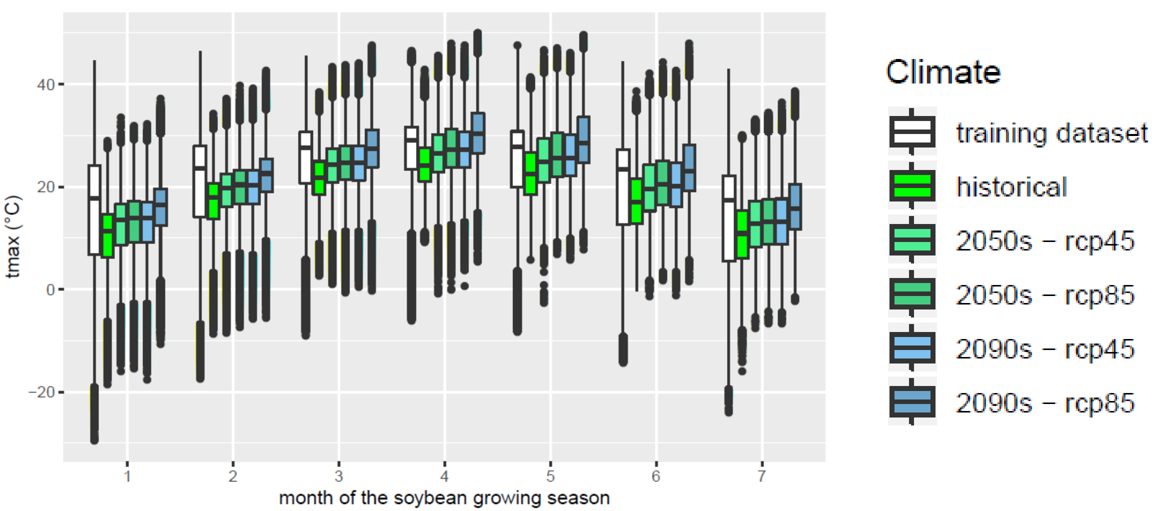
Projections are shown on agricultural area in the year 2000

Guilpart, N., Iizumi, T., & Makowski, D. (2022). Data-driven projections suggest large opportunities to improve Europe's soybean self-sufficiency under climate change. *Nature Food*, *3*(4), 255-265.

No extrapolation of the model beyond the range of data used for training

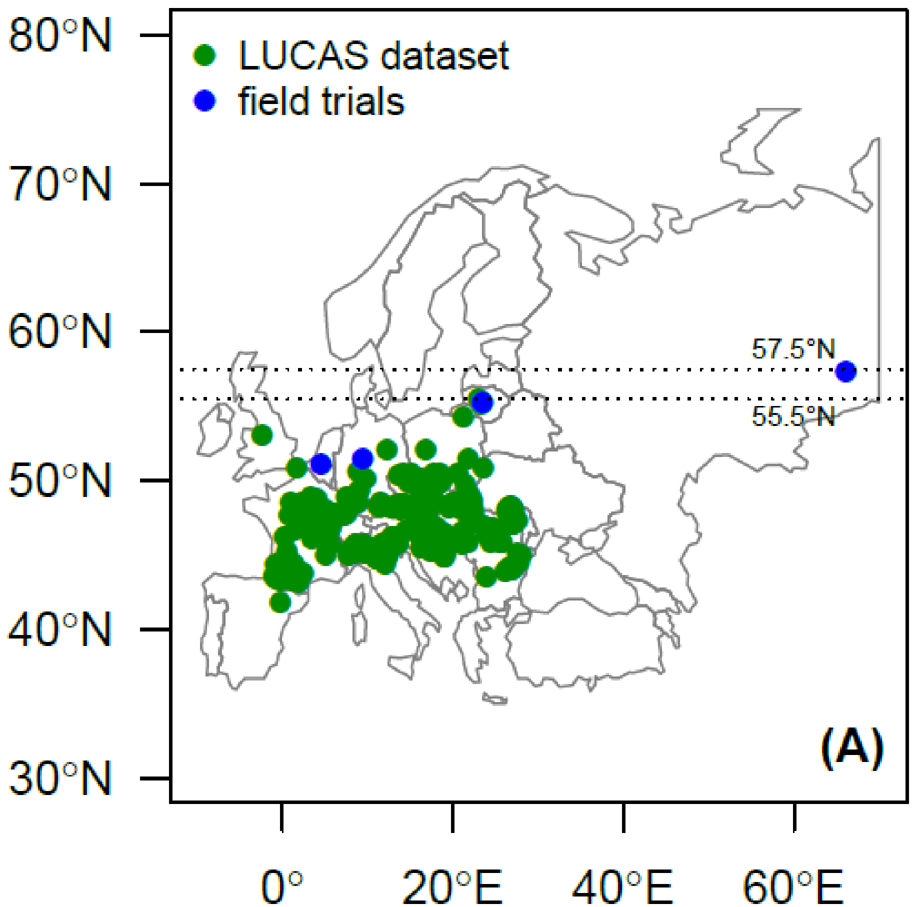






Only **0.03%** of the data in future climate scenarios fall out of the range of climate data used for training

Current evidence of high-latitude soybean in Europe

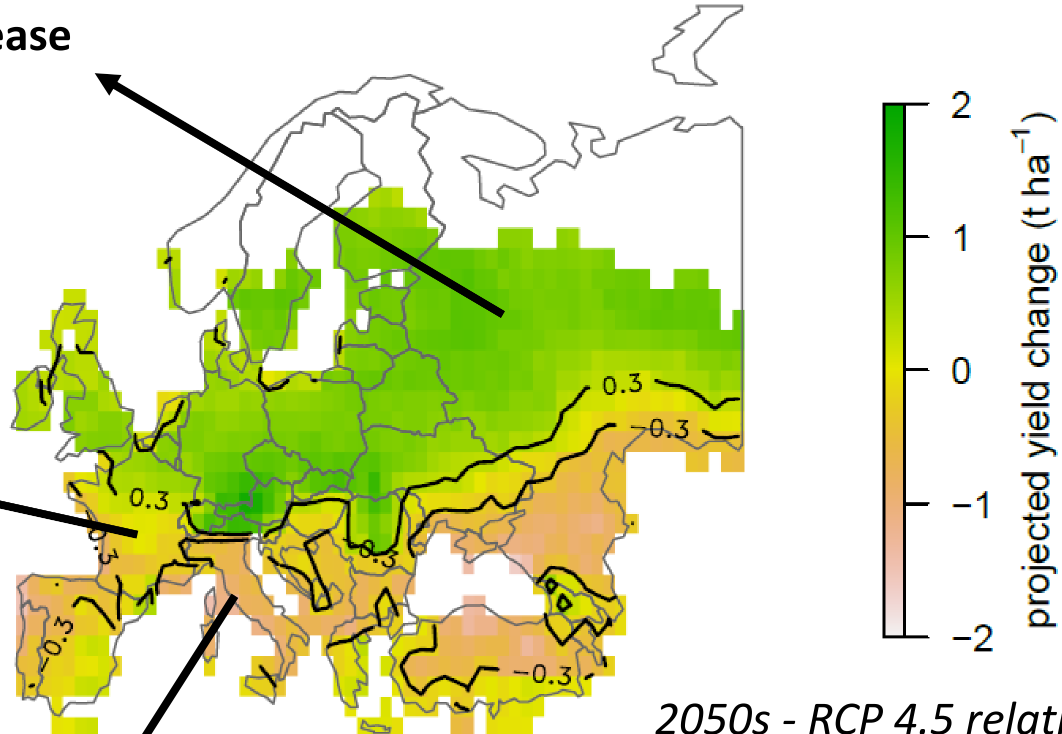


Kühling et al. (2018). Organic Agriculture, 8(2), 159–171.
Kadžiulienė et al. (2016). 20th Baltic Agronomy Forum. Latvia.
Zimmer et al. (2016). European Journal of Agronomy, 72, 38–46.
Pannecoucque et al. (2018). Journal of Agricultural Science, 1–8.

What are the climatic drivers of projected shifts in suitable areas?

Group 2: yield increase
(> +0.3 t ha^{-1})

Group 3:
marginal change
[-0.3 ; +0.3] t ha^{-1}

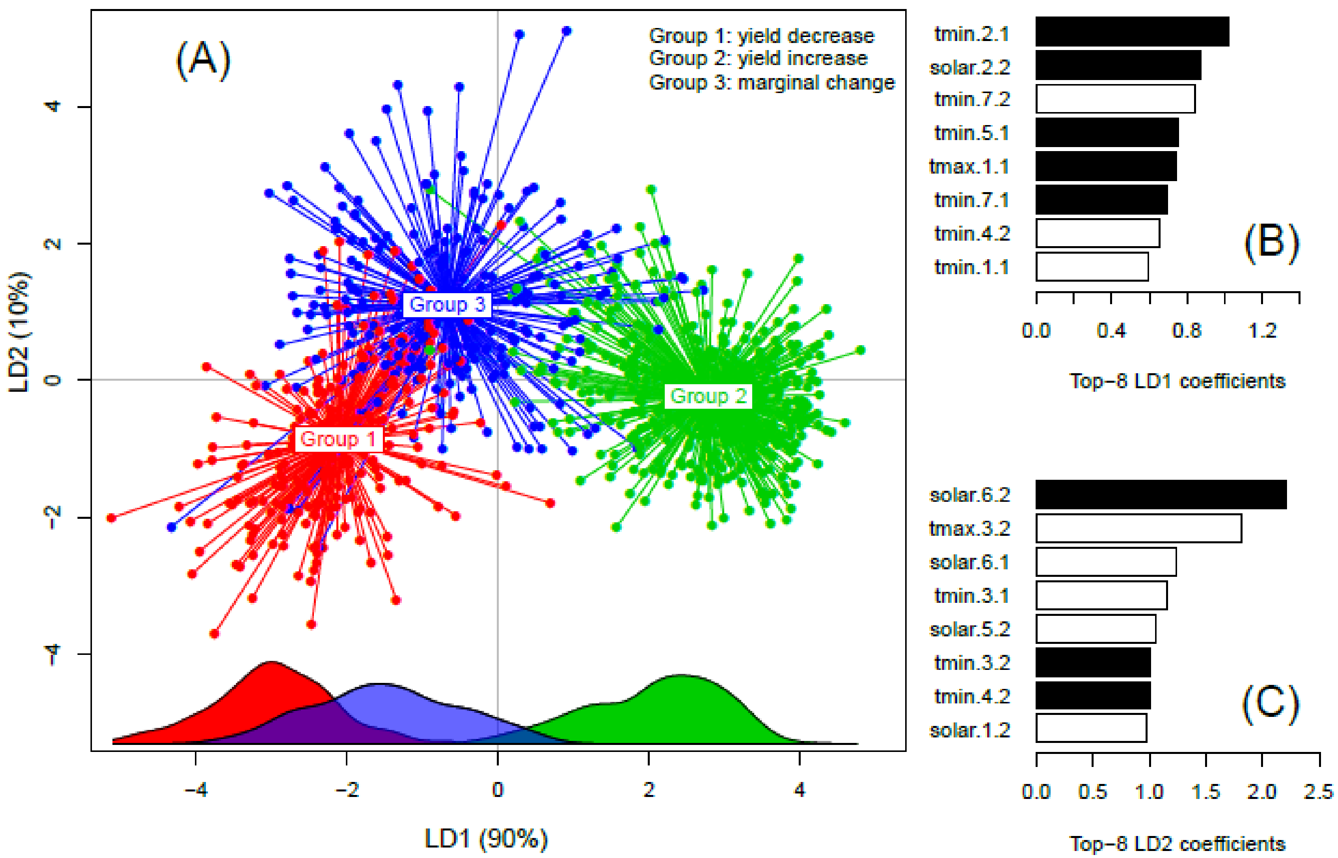


2050s - RCP 4.5 relative to historical climate

Group 1: yield decrease
(< -0.3 t ha^{-1})

Yield changes are mostly driven by temperature changes

Linear Discriminant Analysis (overall accuracy = 89%)



mostly temperature variables

Temperatures associated with yield changes

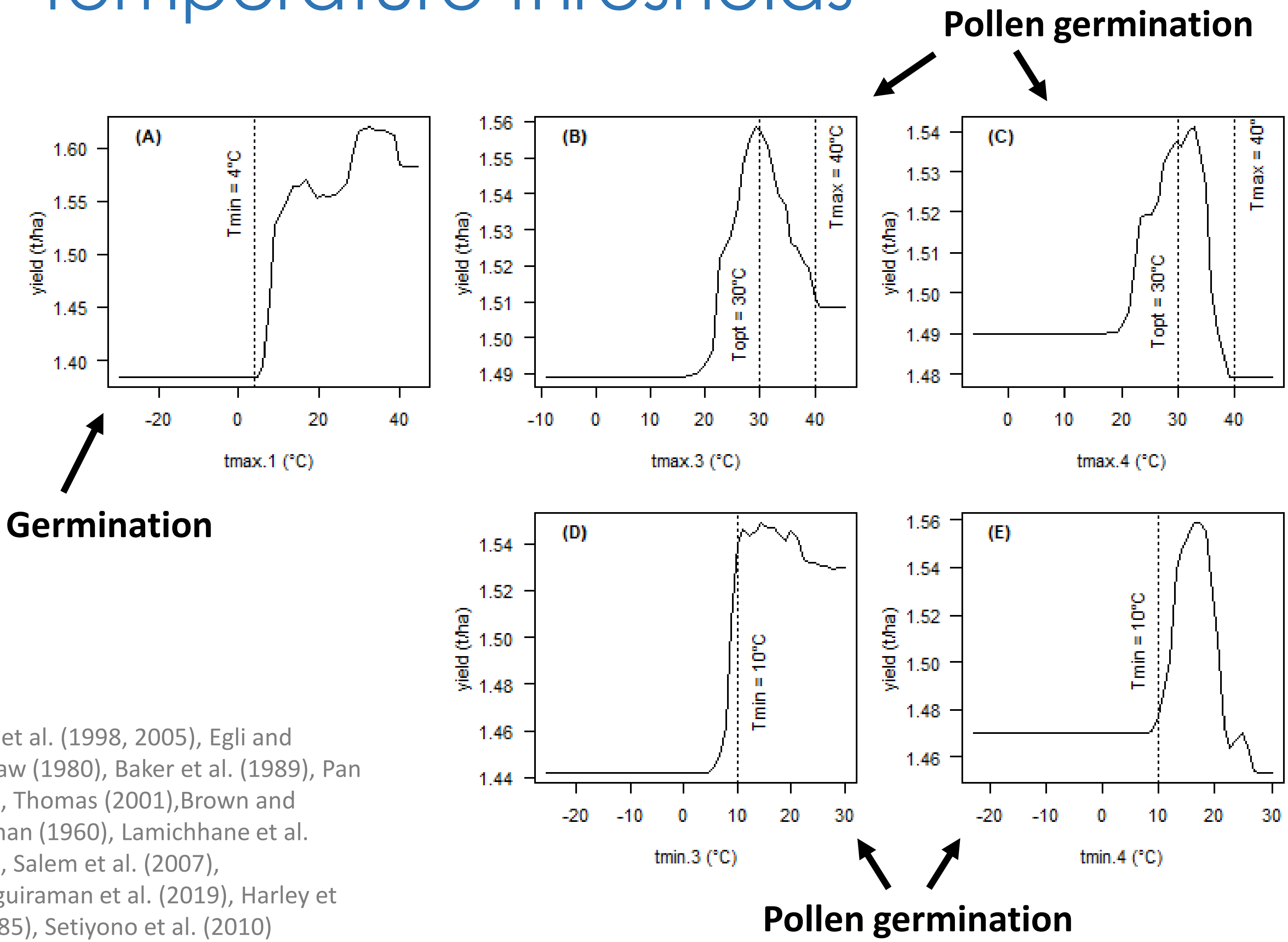
Climate variable	Month*	Group 1 yield decrease		Group 2 yield increase	
		Historical climate	2050s (RCP 4.5)	Historical climate	2050s (RCP 4.5)
Tmax (°C)	1	15,3	16,5	10,6	13,1
	2	21,1	22,6	17,6	19,6
	3	25,5	27,9	21,3	23,8
	4	28,6	31,3	23,4	25,9
	5	28,0	30,9	21,7	24,2
	6	23,4	26,1	16,5	18,9
	7	16,8	18,7	10,1	12,1
Tmin (°C)	1	4,9	5,8	1,7	3,2
	2	9,7	11,1	6,9	8,8
	3	13,3	15,8	10,5	13,2
	4	15,9	18,3	13,0	15,4
	5	15,3	18,0	11,7	14,0
	6	11,5	13,8	7,9	9,7
	7	7,0	8,3	3,3	4,9

* month of the soybean growing season (April to October in Europe)

	Tmin	Topt	Tmax
Pollen germination	10-13	28.5-30	40
Development Post-anthesis	3.6-6	23-26	39-40

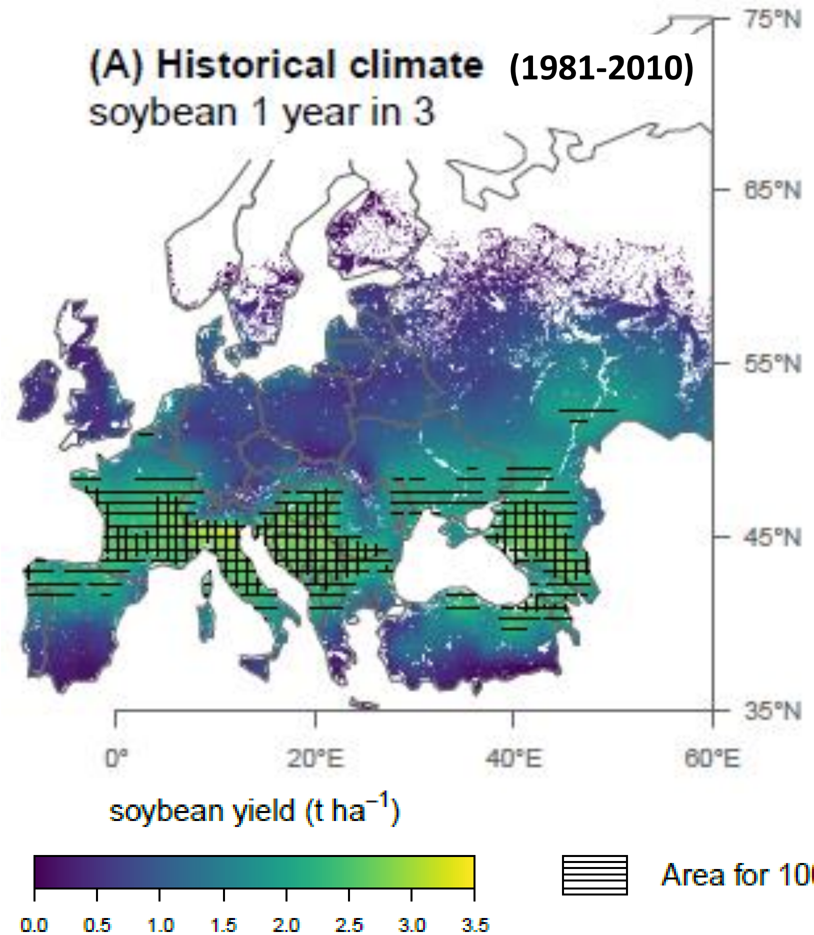
Boote et al. (1998, 2005), Egli and Wardlaw (1980), Baker et al. (1989), Pan (1996), Thomas (2001),Brown and Chapman (1960), Lamichhane et al. (2020), Salem et al. (2007), Djanaguiraman et al. (2019), Harley et al. (1985), Setiyono et al. (2010)

The model captures relevant temperature thresholds



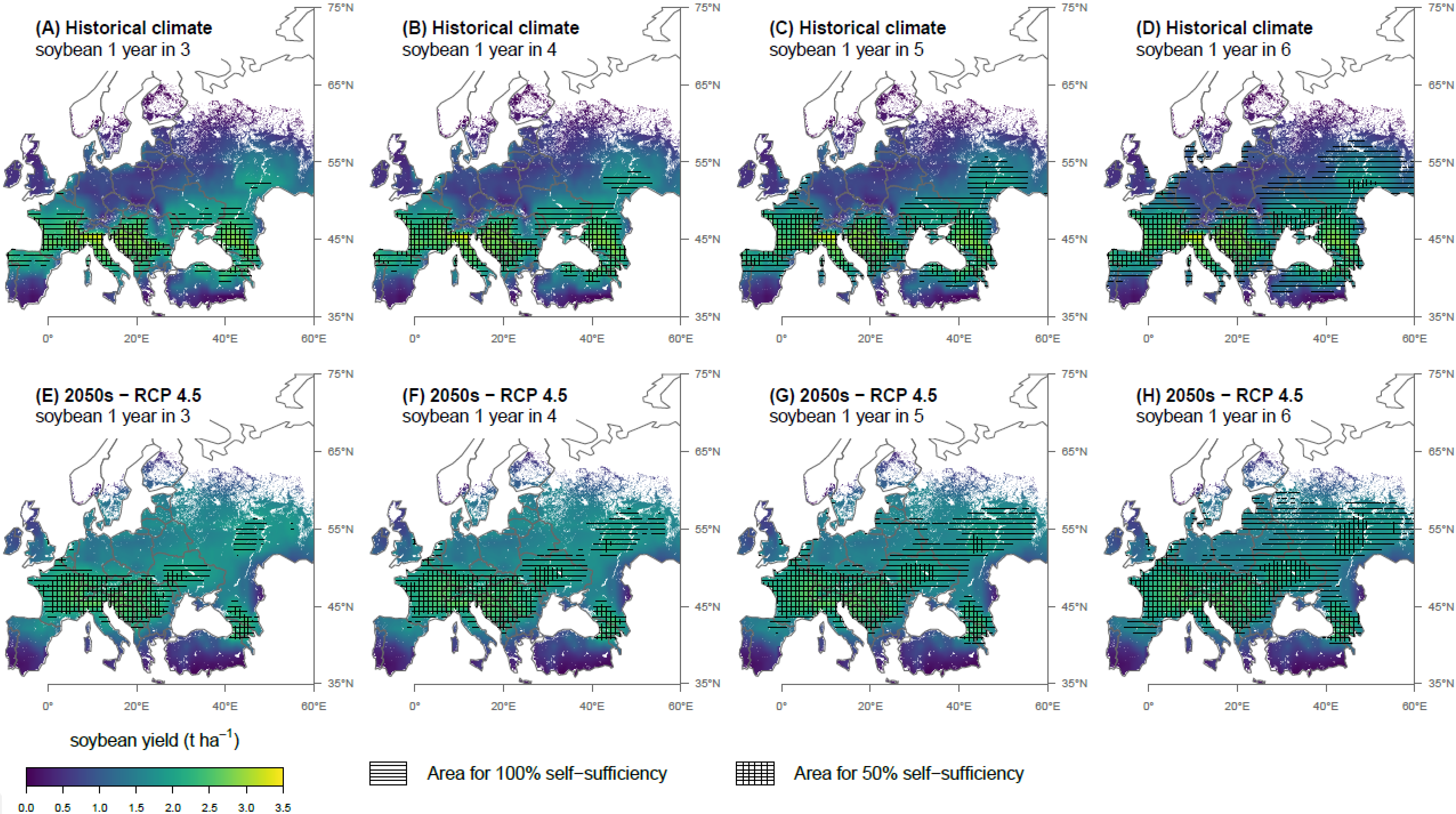
Boote et al. (1998, 2005), Egli and Wardlaw (1980), Baker et al. (1989), Pan (1996), Thomas (2001),Brown and Chapman (1960), Lamichhane et al. (2020), Salem et al. (2007), Djanaguiraman et al. (2019), Harley et al. (1985), Setiyono et al. (2010)

Area requirements for 50% and 100% self-sufficiency



Assumptions

- soybean can only be grown on **cropland** (excluding permanent pastures)
- soybean is preferentially grown in **high-yielding areas**
- Soybean frequency in crop sequence : **1 year in 3 to 6 years**



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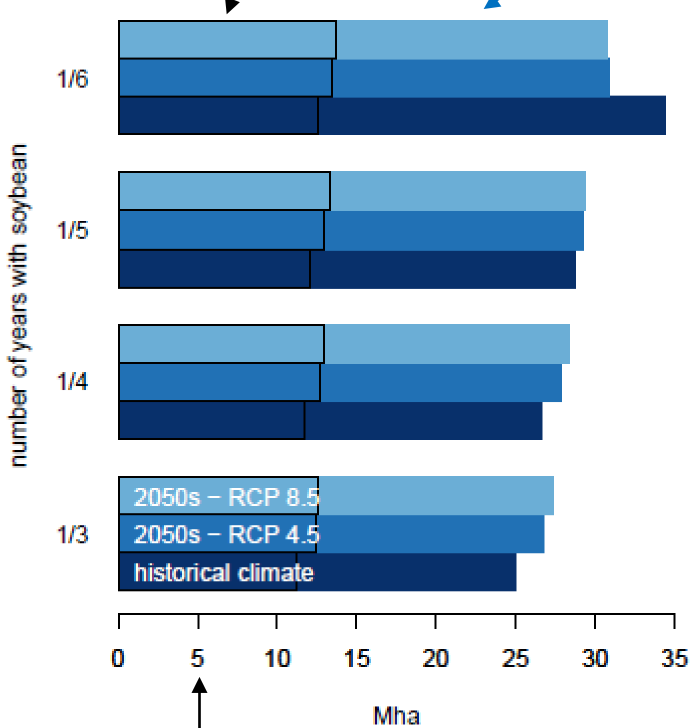
Area requirements for 50% and 100% self-sufficiency

area for 50% self-sufficiency

area 100% self-sufficiency

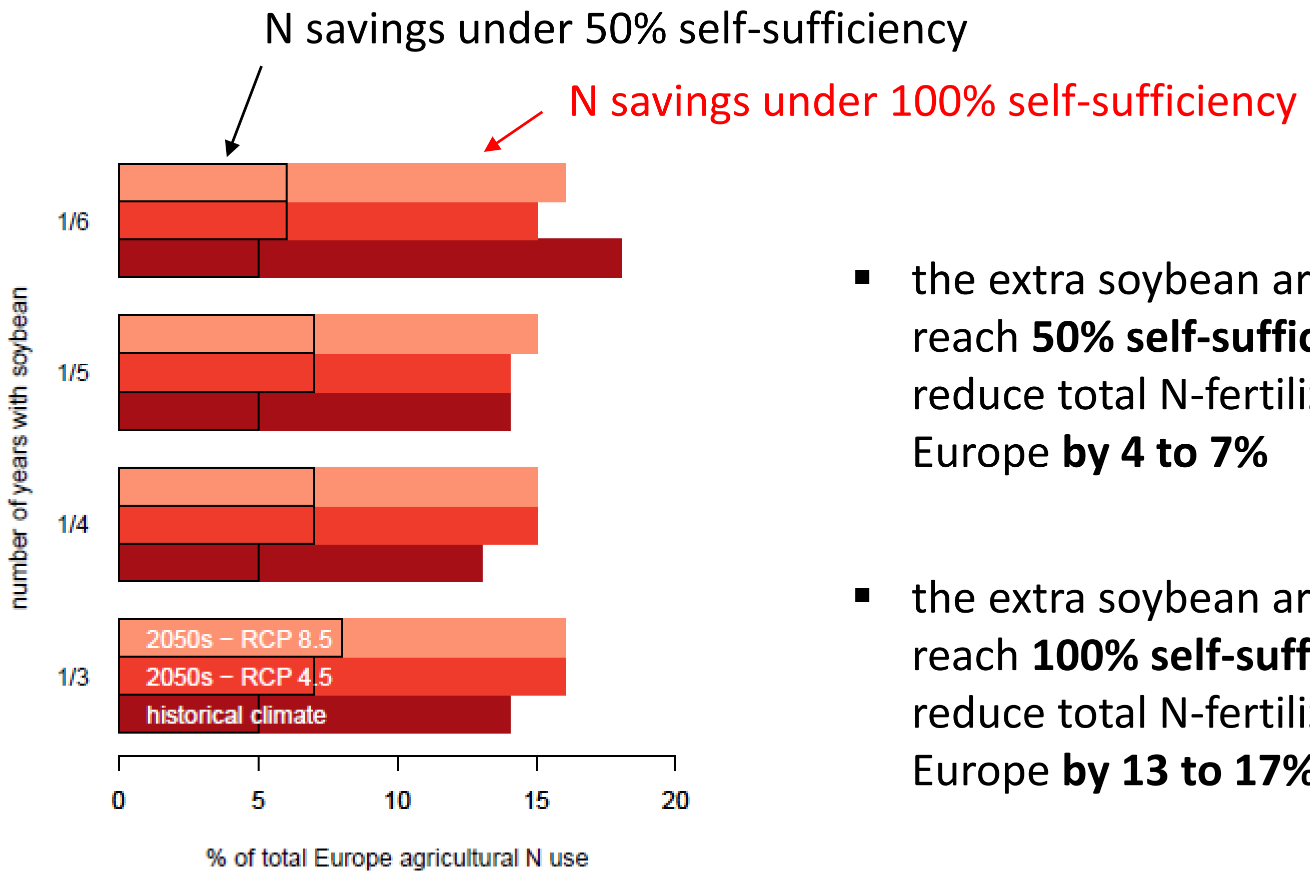


European soybean area is 5 Mha in 2016

- 50 % self-sufficiency is achievable with **4-5% of European cropland.** This represents **2 to 3 times** the current soybean area.

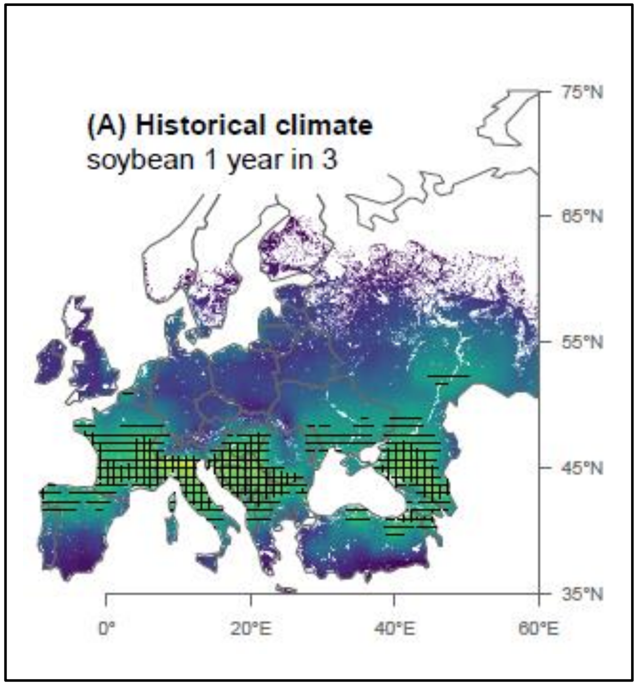
- 100 % self-sufficiency is achievable with **9-12% of European cropland** This represents **5 to 7 times** the current soybean area.

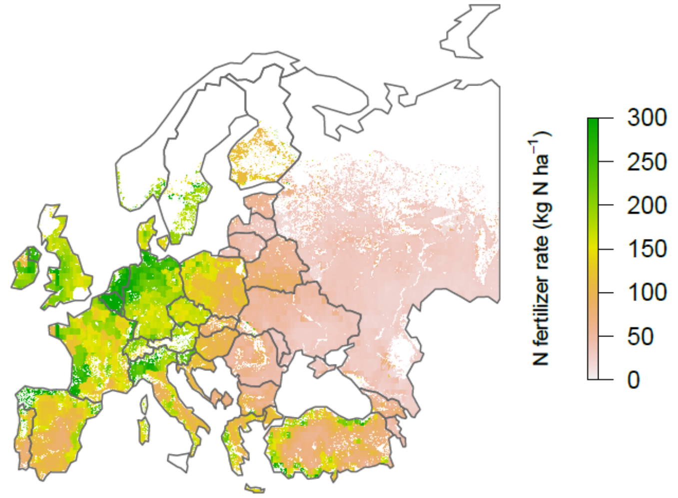
Potential N-fertilizer savings



- the extra soybean area needed to reach **50% self-sufficiency** would reduce total N-fertilizer use in Europe **by 4 to 7%**
- the extra soybean area needed to reach **100% self-sufficiency** would reduce total N-fertilizer use in Europe **by 13 to 17%**

Assumptions for potential N-fertilizer savings estimation

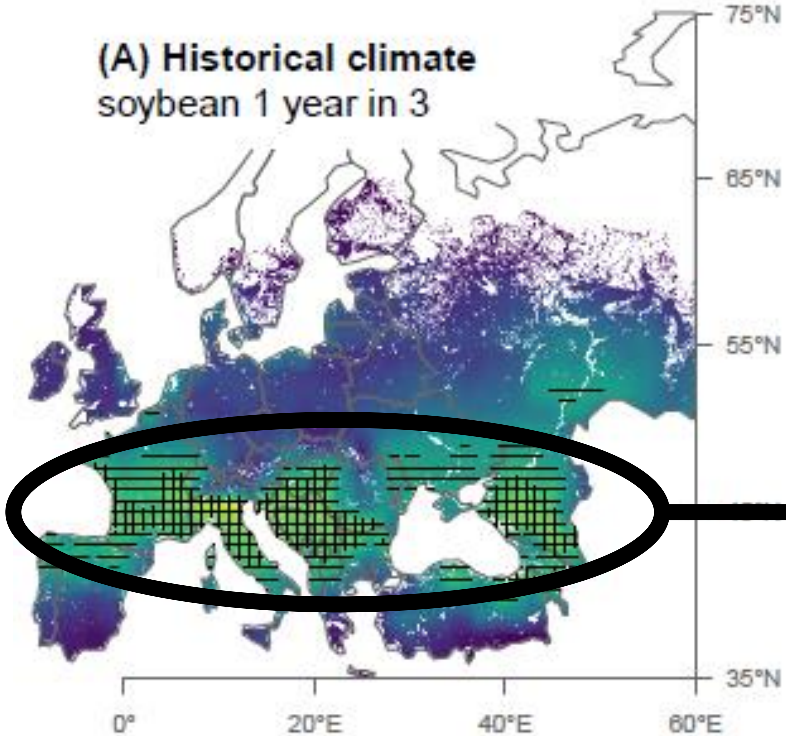




Map of average N-fertilizer rates in Europe
(www.earthstat.org)

- Non-fertilized soybean replaces a N-fertilized crop
- No crop is replaced preferentially by soybean
- No N-fertilizer reduction for crops following soybean

Four crops currently dominate the area needed to achieve 50% and 100% soybean self-sufficiency



1. wheat with 36–43% of the area
2. maize with 14–31% of the area
3. Barley with 10–21% of the area
4. Sunflower with 7–15% of the area

Synthesis

Where can we grow soybean in Europe?

Pretty much everywhere, except the north-east

Will suitable areas be modified by climate change?

Yes they will shift towards the north-east

What are the climatic drivers of projected shift in suitabe areas?

Temperature is the main driver

How much area would be required to reach 50% and 100% self-sufficiency?

5% to12% of European cropland (current <2%)

How much N-fertilizer can be saved from soybean expansion?

From 4-7% (50% self-suffiency) to 13-17% (100% self-suffiency)

Which crop(s) are currently cultivated in projected high-yielding soybean areas?

Four crops dominate: wheat, maize, barley, sunflower

04

Discussion & perspectives

Discussion – on methods

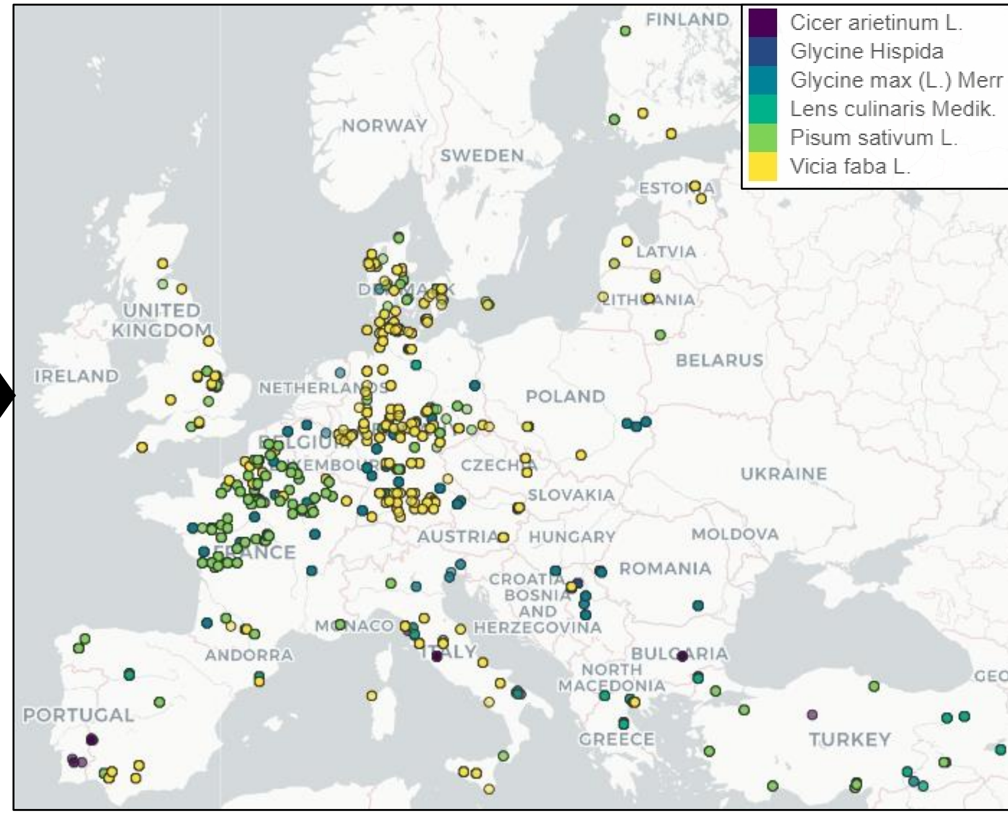
- **On the use of machine learning to model soybean yield**
  - good predictive ability (RMSEP 0.35 t ha^{-1})
  - model behaviour is very consistent with current knowledge on soybean physiology
  - RF handles nonlinear effects and complex interactions with no prior assumption
  - Combining large global climate and yield datasets with machine-learning techniques is a promising approach to study climate impacts on crop production

- **Potential effects of some factors not included in the model**
  - Plant-available water-holding capacity of soils
  - Day length / photoperiod
  - CO_2

- **The need for more soybean data in Europe**
  - model predictive ability decreased when predictions > 1,000 km of training data
  - this is a challenge to assess crop migration due to climate change
  - We started to collect data from field experiments

The European Grain Legume Dataset

Data collection
1. Published papers in scientific journals
2. Data from the EU-FP7 Legato Field Trials Database (publicly available but not published in a journal)
3. Unpublished data from LegValue WP1 Partners's experimental networks were added



About 6500 yield data in 21 countries

soybean (28%), pea (28%), fababean (28%), chickpea (8%), lentils (8%)

Antichi et al. (2021) « The European Grain Legume Dataset » : un jeu de données expérimentales pour prédire le rendement des légumineuses à graines en Europe. Troisièmes rencontres françaises des légumineuses.

Discussion – implications for the food system

- Environmental impacts of soybean expansion in Europe
  + contribute to limit imported deforestation
  + diversifying crop sequence
  + nitrogen fertilizer savings
  + low pesticide use in soybean
  - irrigation water demand (summer crop)
  - the role of animal source foods in food systems
- Soybean expansion and land use change in Europe and abroad
  - The extra 9Mha of soybean needed to achieve 50% Self-sufficiency represents 15% of European wheat production area, and 40% of soybean production area in Argentina
- Land savings from intercropping

Subject : “Quantifying land savings from intercropping corn and soybean in Europe under climate change”

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Talents d'une planète soutenable

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PARIS-SACLAY

27 Juin 2022

Thanks for your attention!

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