Changes in yield stability from input-driven agricultural intensification

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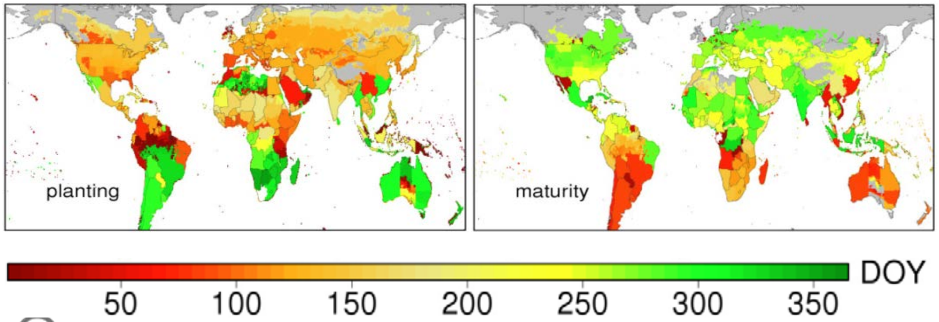
The Agricultural
Model Intercomparison
and Improvement Project

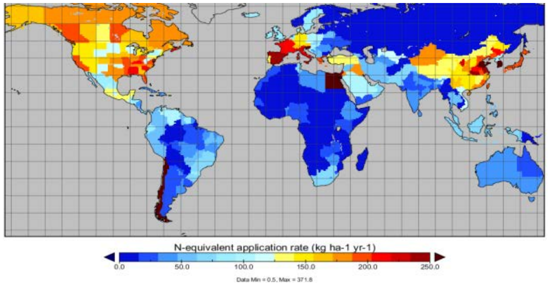
AgMIP, ISIMIP and GGCMI

- **AgMIP is the Agricultural Model Intercomparison and Improvement Project**
- **ISIMIP is the InterSectoral Impact Model Intercomparison Project**
- **GGCMI is the Global Gridded Crop Model Intercomparison of AgMIP, coordinating the Agriculture (crop modeling) sector of ISIMIP**

GGCMI Phase 1: understanding the past

- **Ten reanalysis-based historical weather products spanning 1901-2012**
- **14 GGCMs supplying data, 4 crops, all land area, rainfed and irrigated conditions**
- **Different levels of harmonization on fertilizer, sowing, maturity**
- **Basis for model evaluation and understanding of general mechanisms**





Elliott et al. 2015

GGCMI Phase 1: output examples

- General model evaluation: Müller et al. 2017
  - Online model evaluation tool at https://mygeohub.org/tools/ggcmevaluation
- Interannual yield variability: Frieler et al. 2017
- Yield damage from T exposure: Schauberger et al. 2017

How do inputs affect yield stability?

- **Agriculture needs to increase production to satisfy growing demand (population, diets)**
- **Instability in crop production is a problem in food security**
- **GGCMI phase 1 protocol design allows for studying the effects of intensification through additional nutrient and/or water supply**

Study design

- 10 crop models, WFDEI weather data
- Harmonized fertilizer vs. unlimited fertilizer
- Rainfed vs. irrigated (unlimited water supply)
- Settings

	Current irrigation patterns	Full irrigation
Current fertilizer inputs	actual	uN: unlimited nutrients
Unlimited fertilizer inputs	uW: unlimited water	uWN: unlimited water and nutrients

Metrics

- **Measure of relative yield variability**
  - variation around a high mean value is less harmful than the same absolute variation around a low mean

$$CV = \frac{\sigma_x}{\bar{x}} * 100\%$$

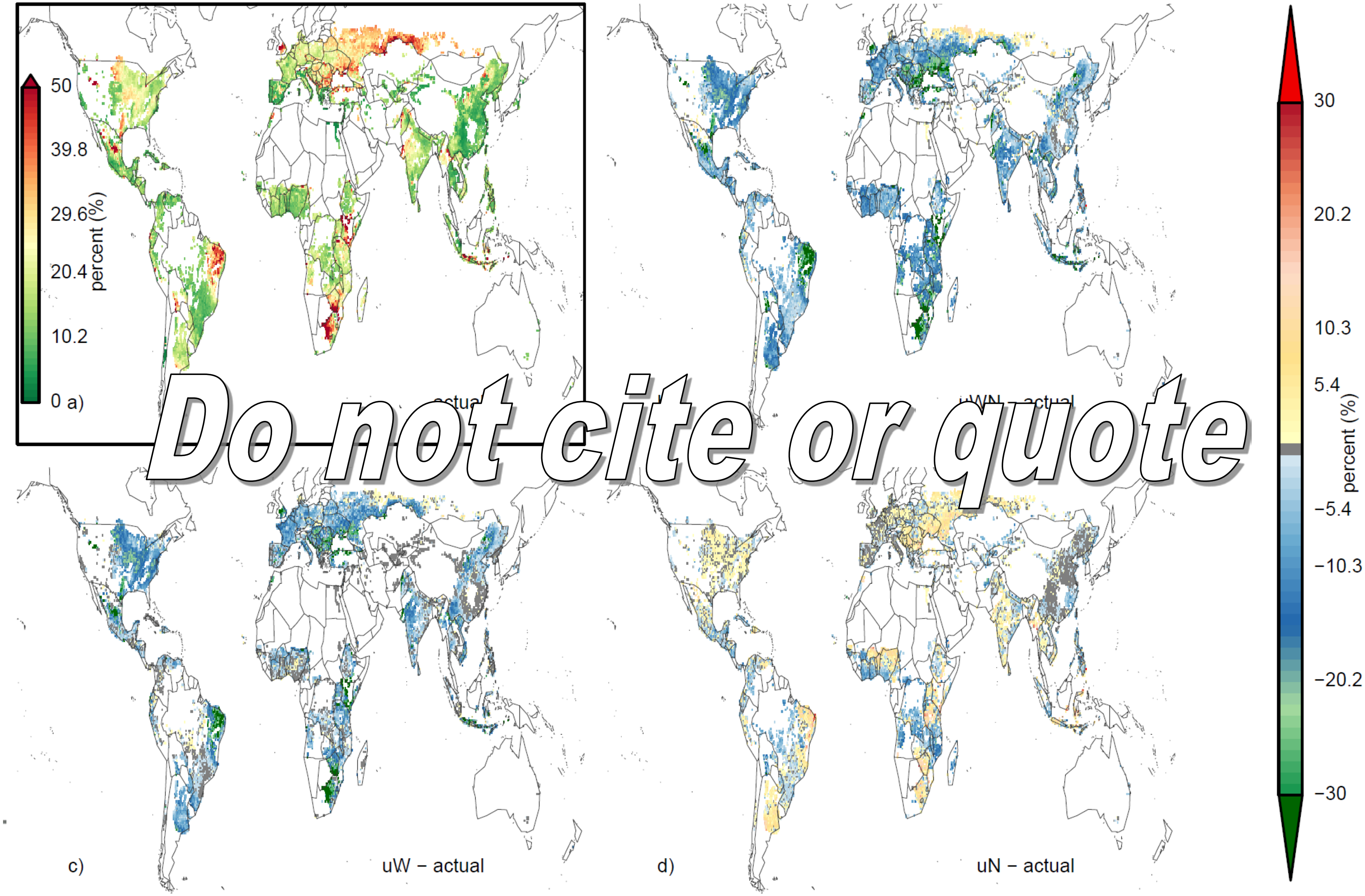
- **Yield dent**
  - Distance between 3 lowest yielding years (Y10) and 30-year mean

$$Yd = \bar{x} - Y_{10}$$

Low yield CV (green) associated with more water, high CV (orange) with more nutrients

Crop	GGCM	actual	uWN	uN	uW
Maize	pDSSAT	3.93	3.31	5.08	2.37
	EPIC-Boku	3.41	2.30	3.53	1.97
	EPIC-IIASA	2.88	2.51	2.97	1.89
	GEPIC	5.10	3.08	4.70	2.88
	pAPSIM	4.13	2.77	4.57	1.79
	PEGASUS	3.82	1.37	2.71	4.16
	CLM-Crop	2.45	2.37	2.44	2.58
	EPIC-TAMU	4.00	2.85	3.90	2.27
	ORCHIDEE-crop	NA	NA	NA	NA
	PE[illegible]	4.31	1.65	3.70	1.44
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wheat	[illegible]	[illegible]	8.73	[illegible]	[illegible]
	EPIC-Boku	3.53	2.25	3.57	2.26
	EPIC-IIASA	8.86	7.93	9.22	8.01
	GEPIC	8.13	7.46	8.31	7.68
	pAPSIM	9.64	8.97	9.86	8.81
	PEGASUS	2.93	2.28	3.46	3.40
	CLM-Crop	3.54	1.48	3.50	1.32
	EPIC-TAMU	8.37	6.84	8.66	7.00
	ORCHIDEE-crop	8.75	6.19	8.82	6.10
	PEPIC	2.94	1.60	3.14	1.44
	median	8.13	6.84	8.31	7.00
	FAO	2.34	NA	NA	NA

Spatial patterns of yield CV (maize)



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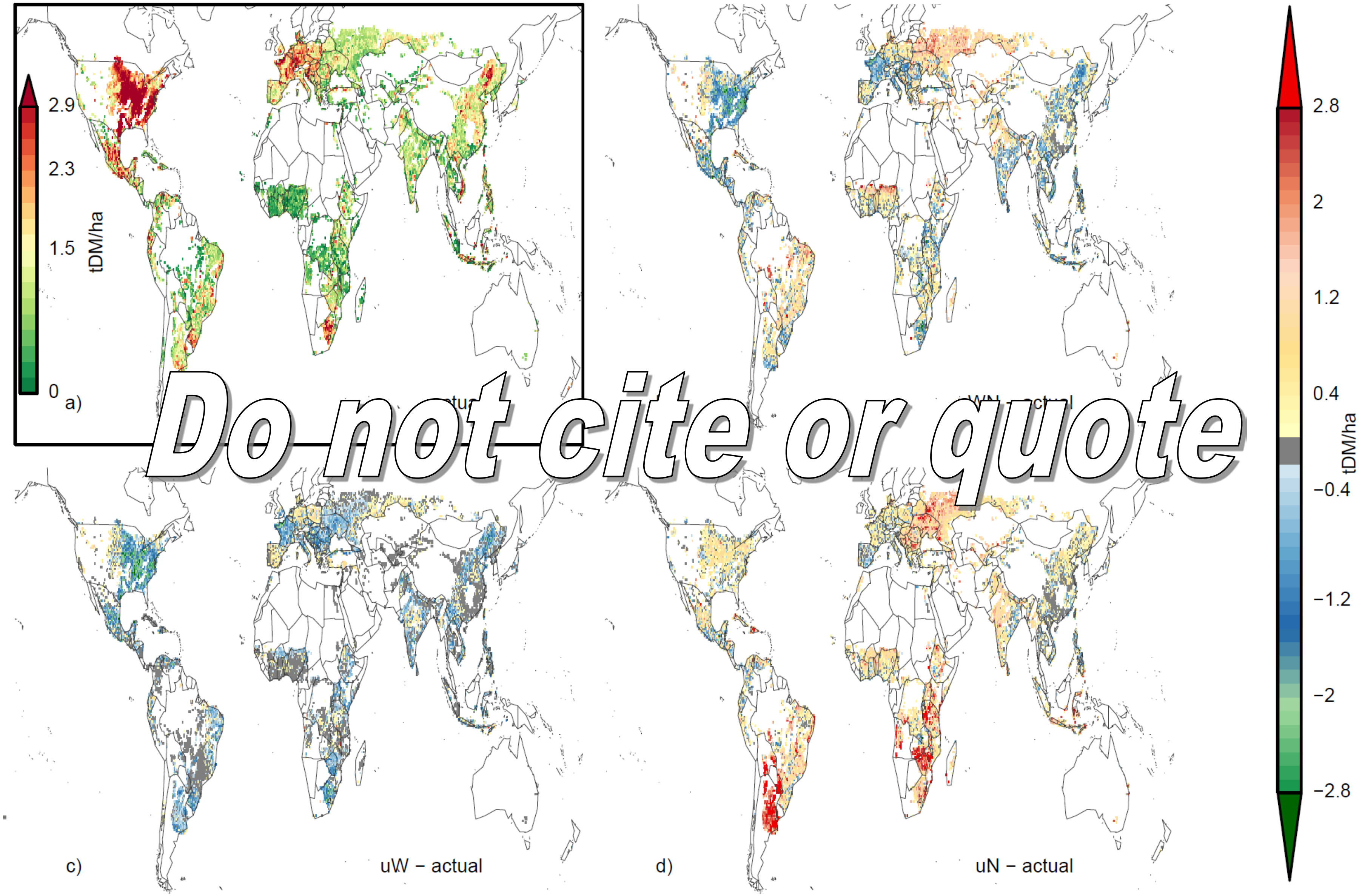
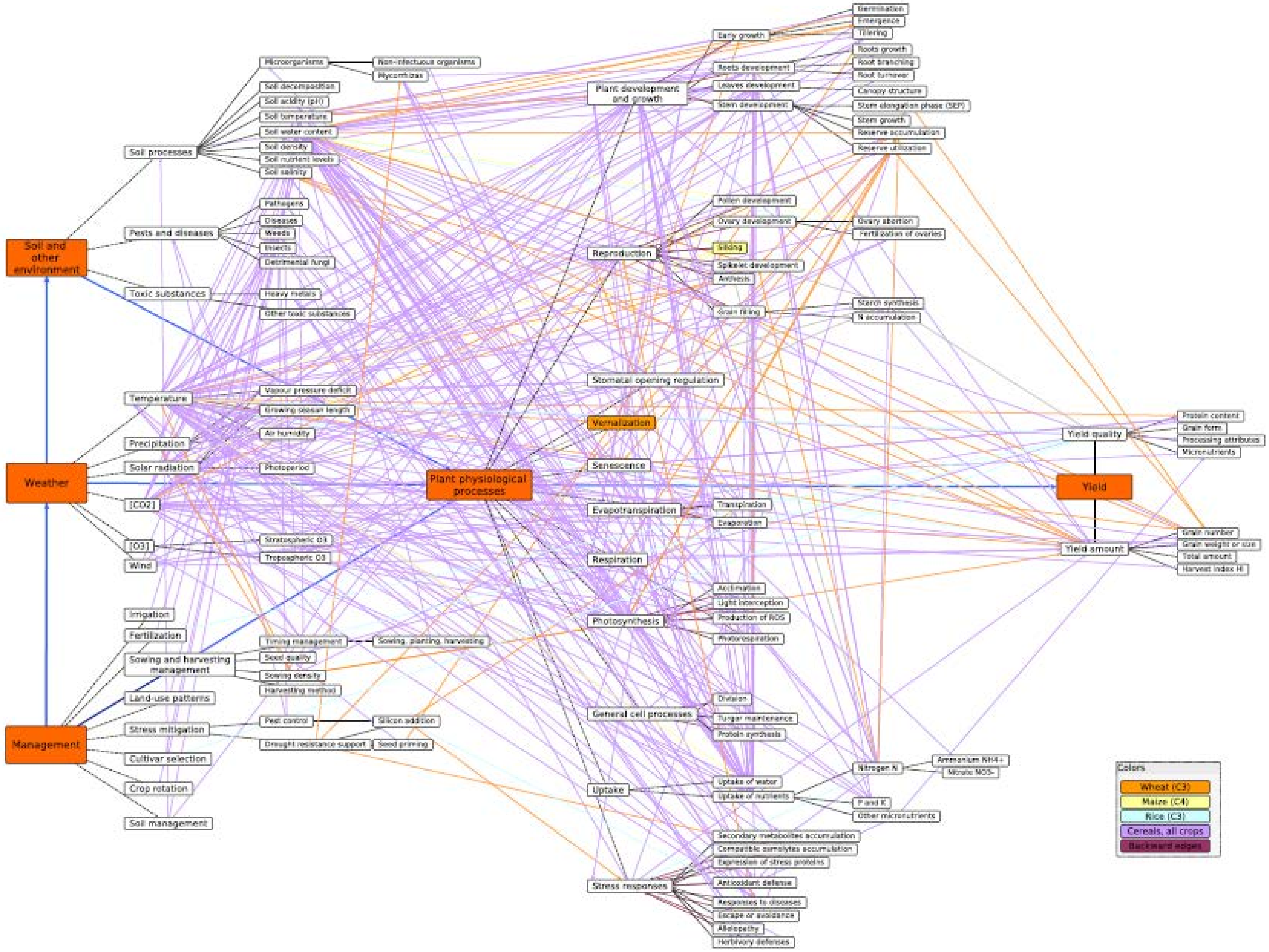


Cornucopia of mechanisms driving yield variability



Schauberger et al. 2016

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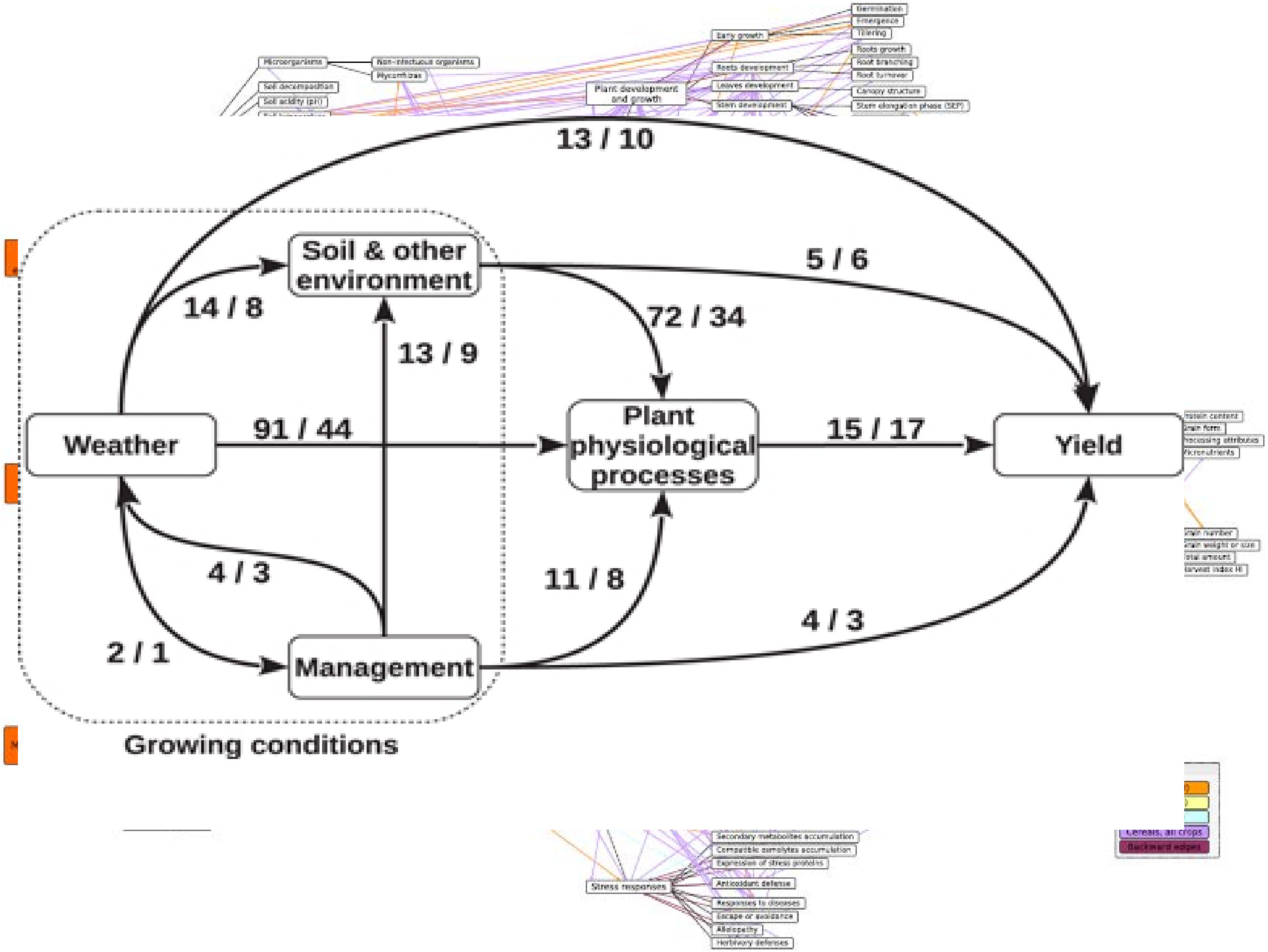

Schauberger et al. 2016

Ambiguous effects of intensification on yield stability

- **More water:**
  - Typically reduces CV by increasing mean yields and especially increasing yields of bad years (= dry years)
  - Where effects are large and water is available, irrigation is often already installed
- **More nitrogen:**
  - Often increases CV, as individual bad years are typically not bad years because of nutrient supply, so they are as bad as before
  - Can also decrease CV if increase in mean yield overrules difference between good and bad years

Implications

- **Agricultural intensification can lead to decreases in yield stability, especially since fertilizer-driven intensification is more likely.**
- **Therefore intensification needs to be accompanied with additional measures to stabilize food supply: trade, storage**
- **Patterns are similar across different crop models and thus robust. Differences warrant further research**

Next steps in GGCMI

- Phase 1: further analysis, data description paper, data publication
- Phase 2: CTWN-A, a sensitivity analysis on Carbon dioxide, Temperature, Water, Nitrogen, Adaptation
  - Most simulation data submitted, output processing
  - In-depth understanding of model behavior
  - Response type classification
  - Emulator design
  - Targeted model improvement
  - …
- Phase 3: new future projections with ISIMIP3?

Find out more and get involved

- http://www.agmip.org/ag-grid/ggcmi/
- https://www.isimip.org
- https://www.pik-potsdam.de/members/cmueller
- http://www.rdcep.org/directory/joshua-elliott

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