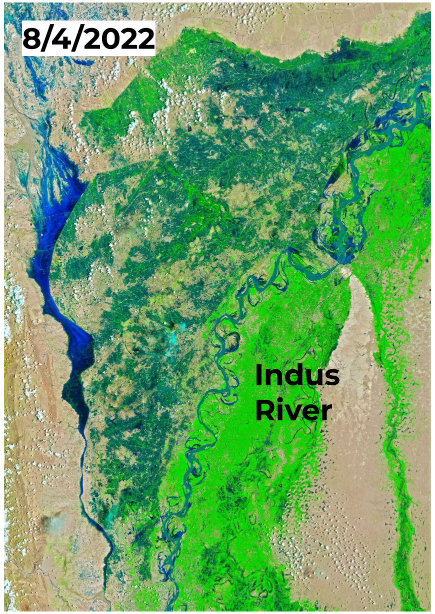
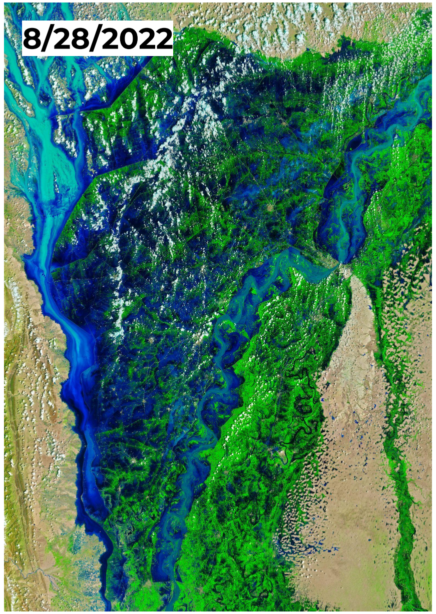
Eating our cake without losing it:

Key questions for achieving global food security and environmental goals

Sonali Shukla McDermid
Associate Professor, Environmental Studies, NYU

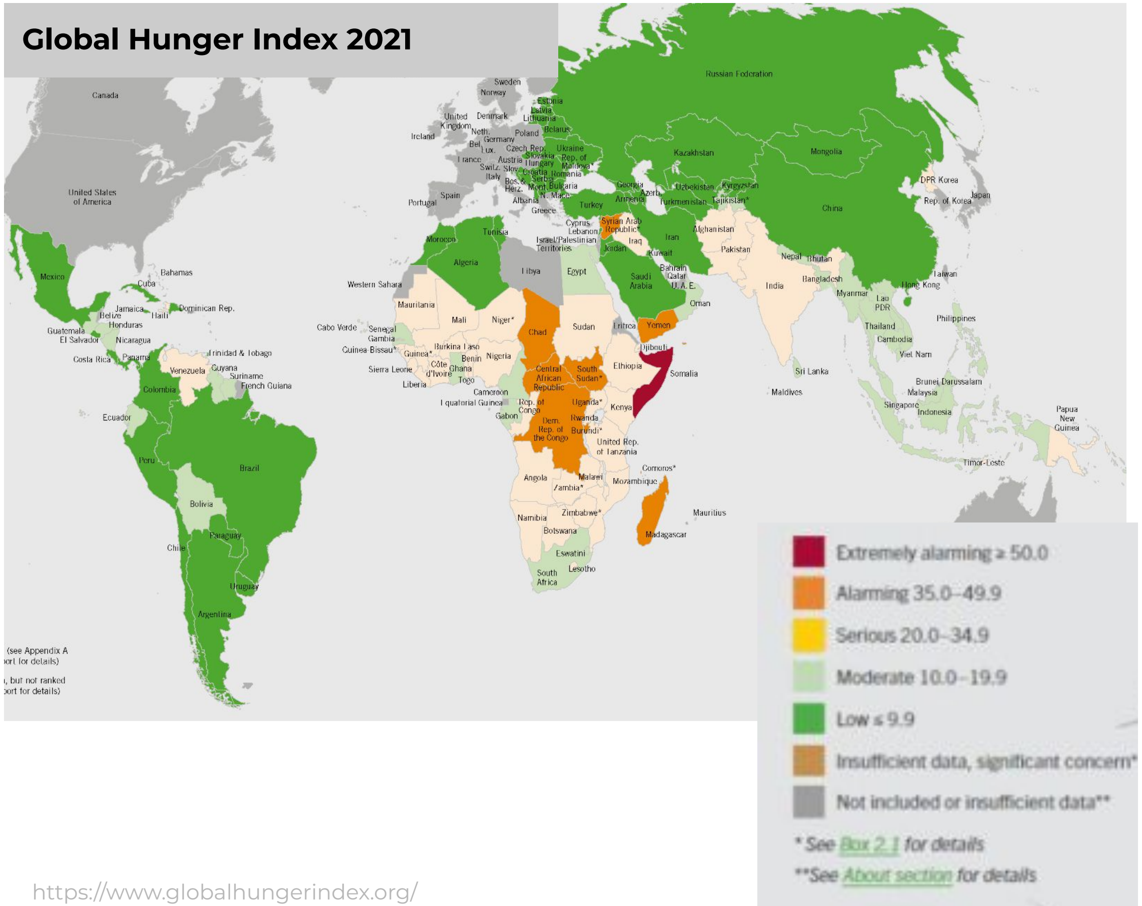
Land Surface Modeling Summit
Oxford, UK
9/12/2022





False-color Landsat 8/9, NASA Earth Observatory,

The Lens of Food Security



After holding steady from 2014 to 2019 (500-600 million), undernourishment climbed to ~9.9% of global population in 2020

~768 million people in the world faced hunger in 2020
(118-161 million more people than in 2019)

https://www.globalhungerindex.org/

Food Security and Environmental Goals

Breaking it down

- **The lens of food security**
- Climate impacts on food security
- Agricultural impacts on other Earth systems
- Needs for solution space

The Lens of Food Security

Stability

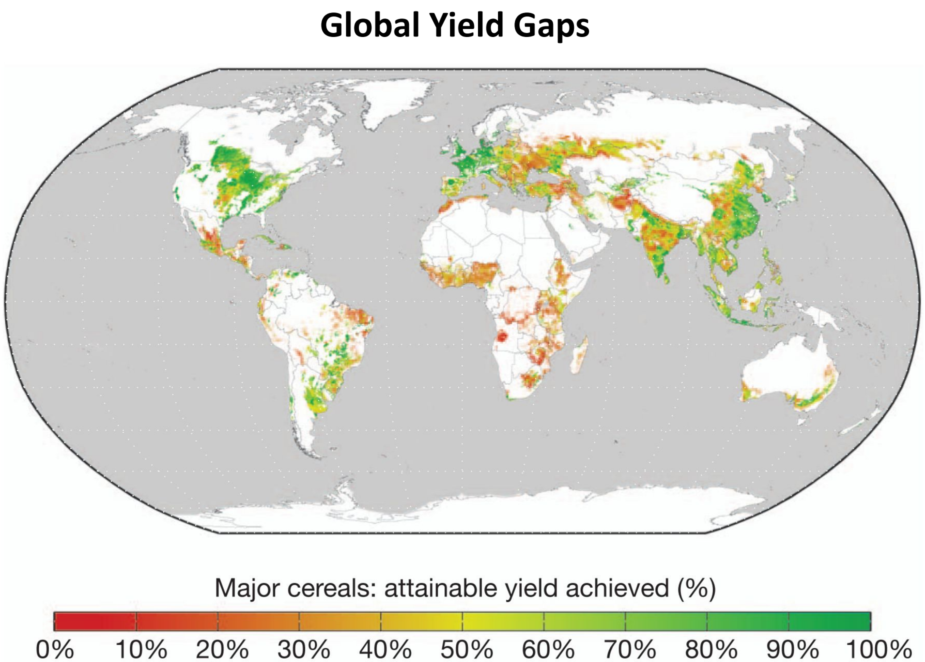
Physical availability of food

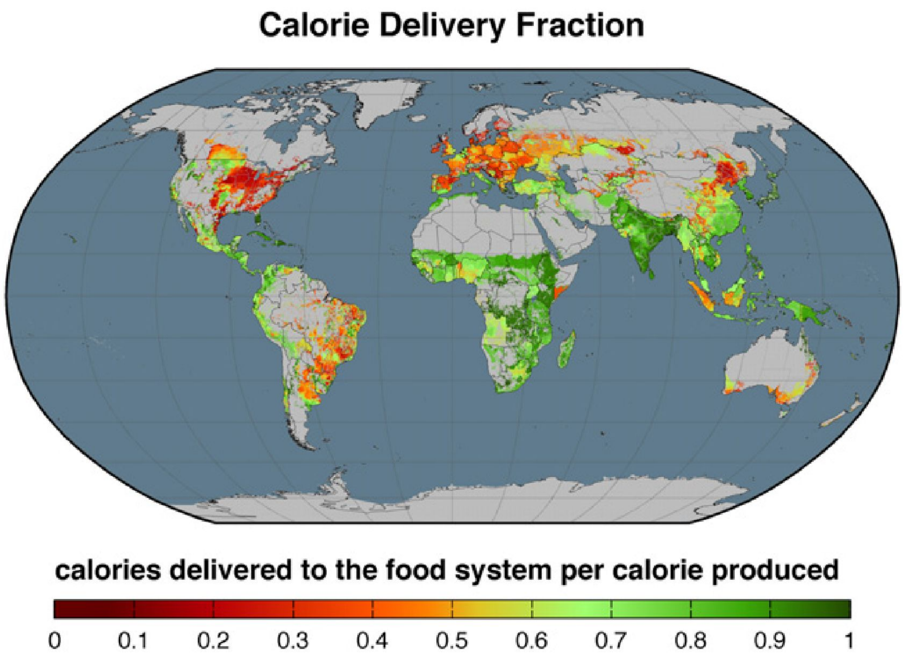
Economic & physical access to food

Food utilization

UN FAO; Sustainable Development Goals

The Lens of Food Security

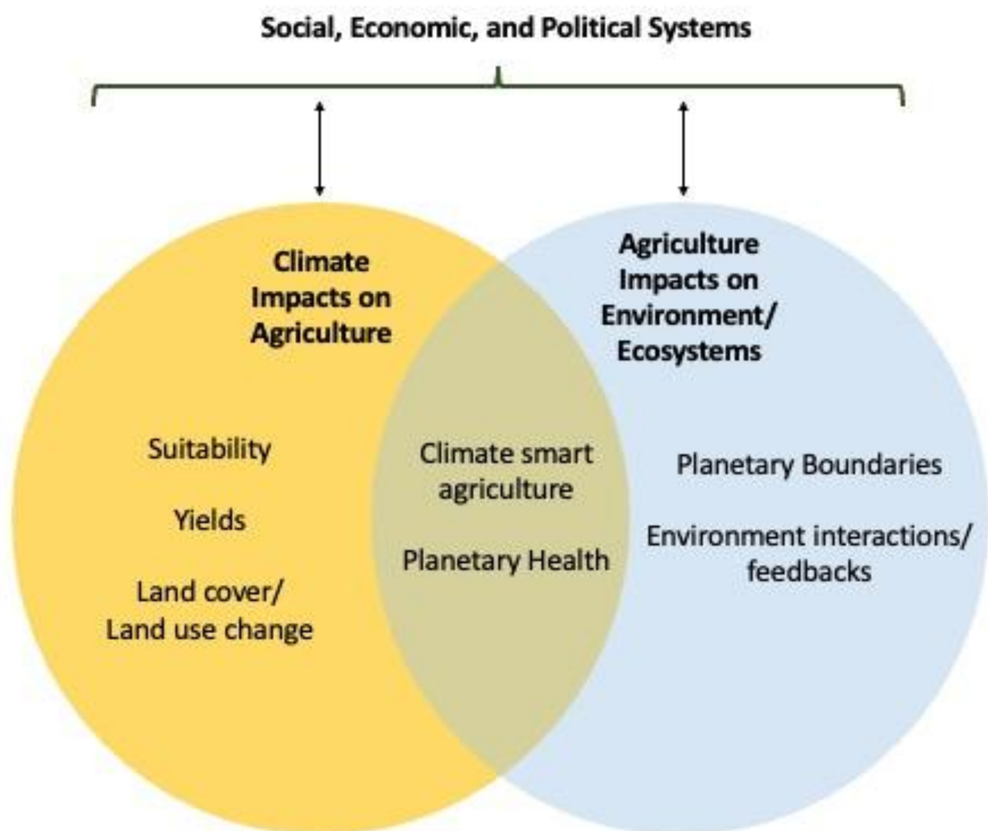




To what end is land being used?

Mueller et al 2012; Cassidy et al 2013

The Lens of Food Security



Encourage land modeling efforts to consider impacts, trade-offs and co-benefits of LULCC through the lens food security

How do known sources of uncertainty limit our understanding of key climate<->agriculture interactions?

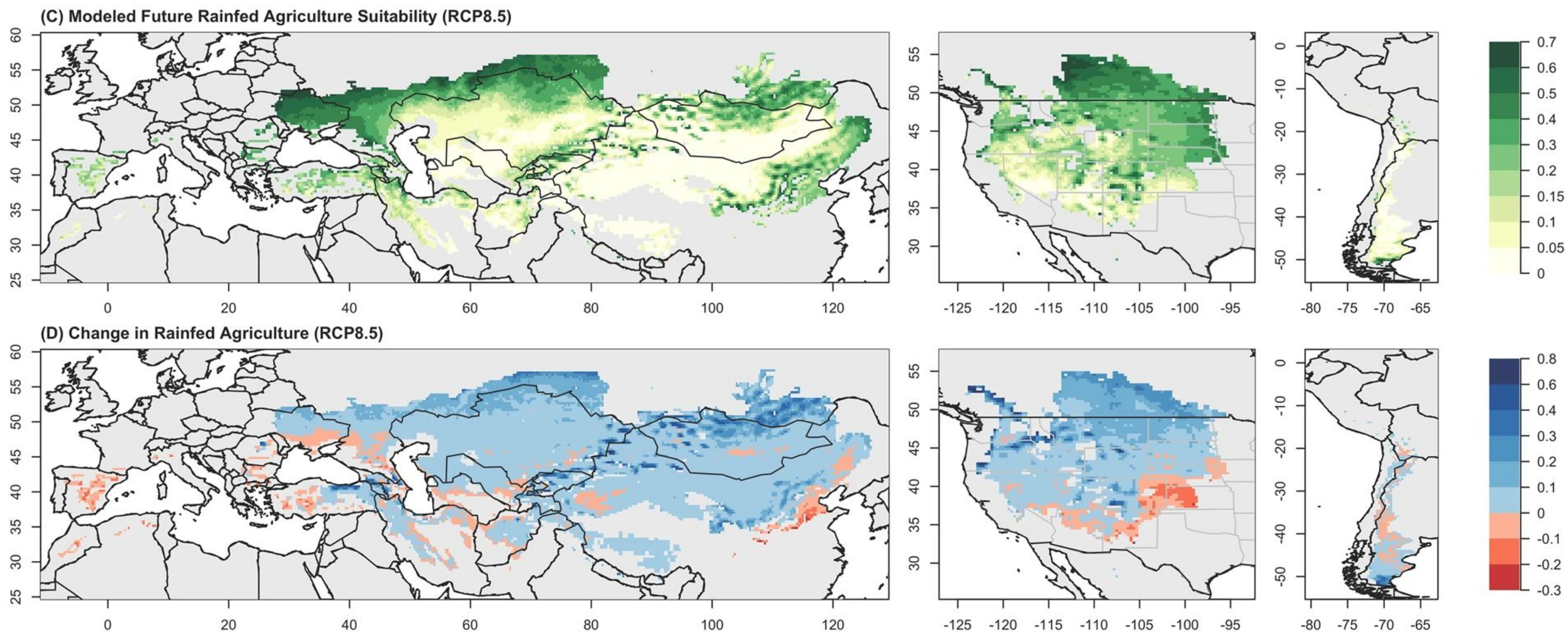
UN FAO; Sustainable Development Goals

Food Security and Environmental Goals

Breaking it down

- The lens of food security
- **Climate impacts on food security**
- Agricultural impacts on other Earth systems
- Needs for solution space

Climate change impacts on food security



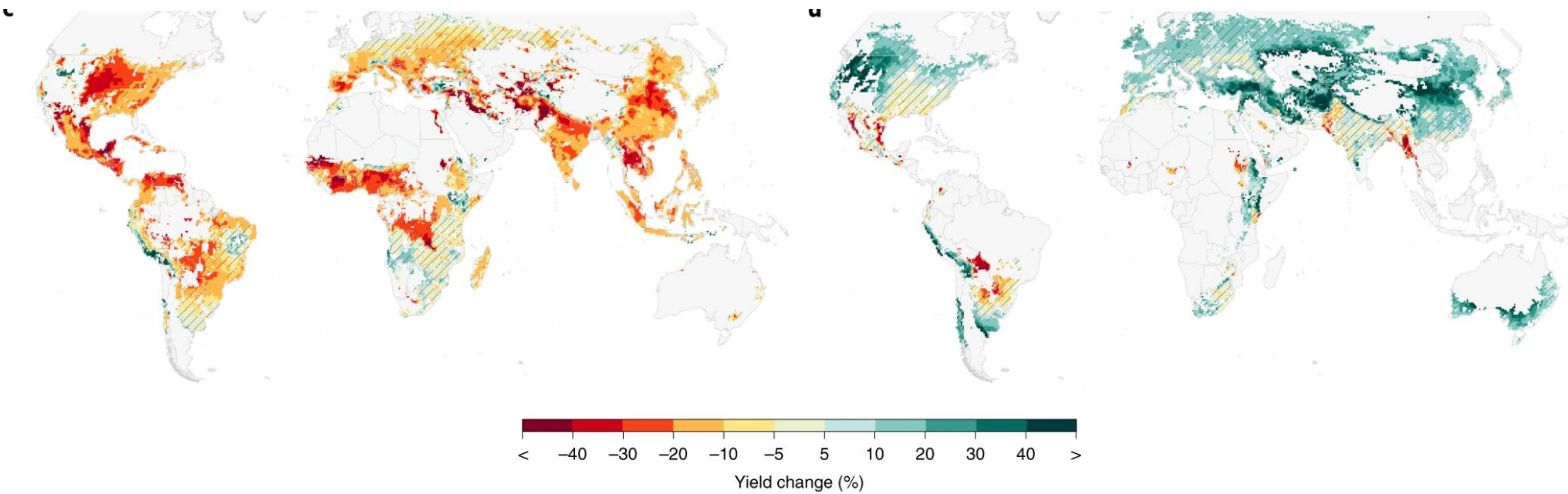
Models can help assess changing suitability and potential production, and adaptation (e.g. crop migration).

However, climate -> crop impacts may not consider (or “double count”) important climate <-> crop feedbacks,

Bradford et al 2017; Sloat et al 2020

Climate change impacts on food security

GGCMI Modeled Maize **GGCMI Modeled Wheat**

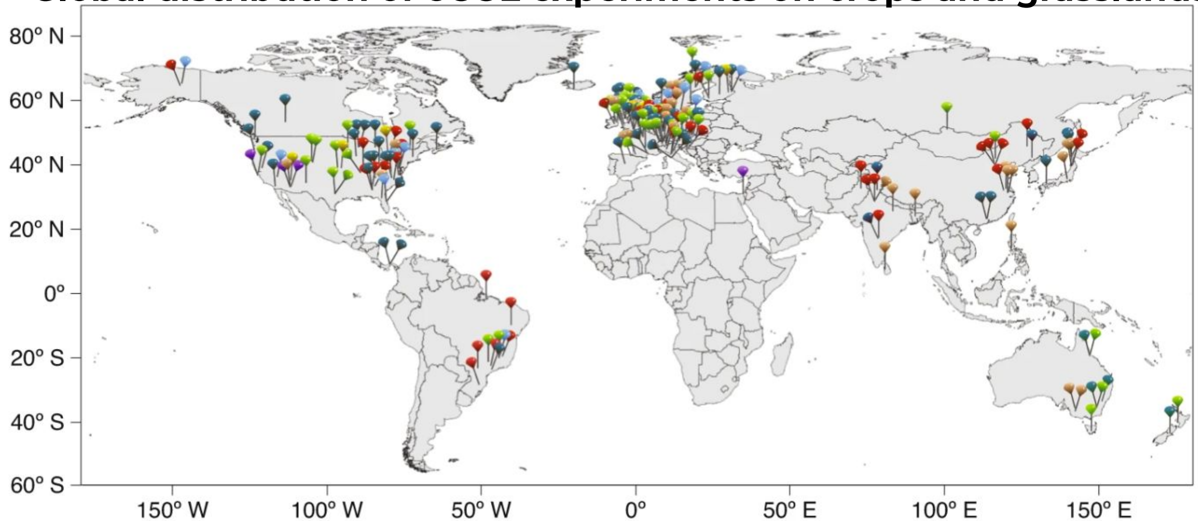


Global gridded crop models with climate forcing data allow future projections of yield, as well as an exploration of important crop physiological processes.

Jagermeyr et al 2021

Climate change impacts on food security

Global distribution of eCO2 experiments on crops and grasslands

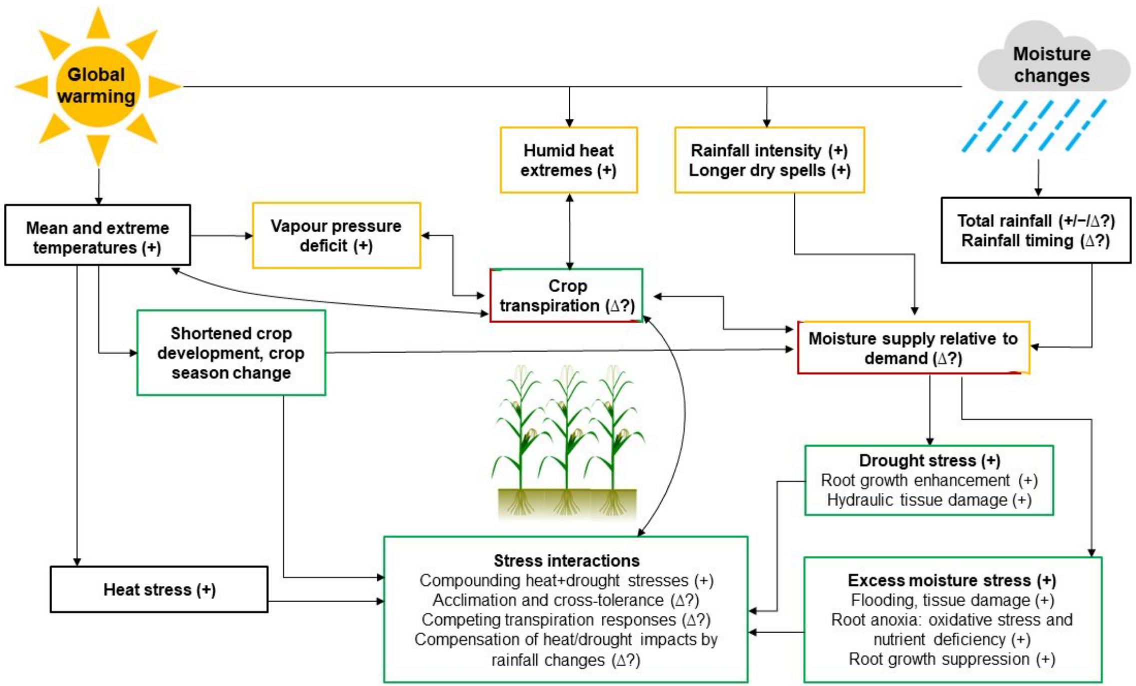


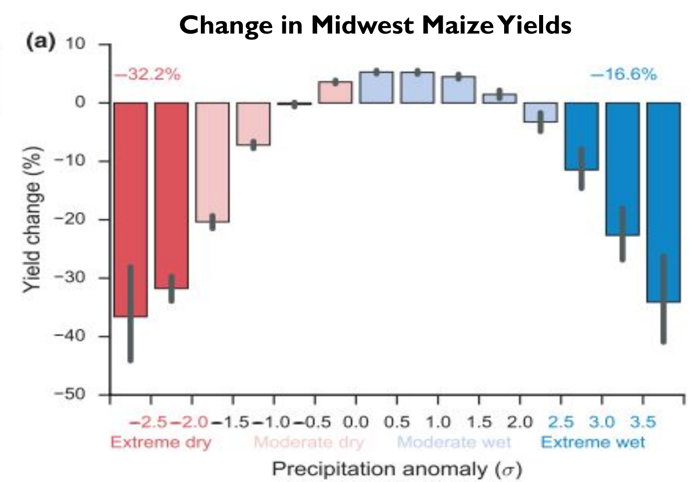
However, much of the detailed management information required comes from industrialized agricultural zones

E.g. CO2 effects now standard in crop model simulations. Data is lacking for important food security crops across important growing regions. Recent work also shows losses in micronutrients (Fe, Zn, etc.)

Toreti et al 2020

Climate change impacts on food security





Most models still do not capture climate extremes well, much less compound extremes. What we do know again often comes from where data is more available. However, implications for food security and adaptation are profound

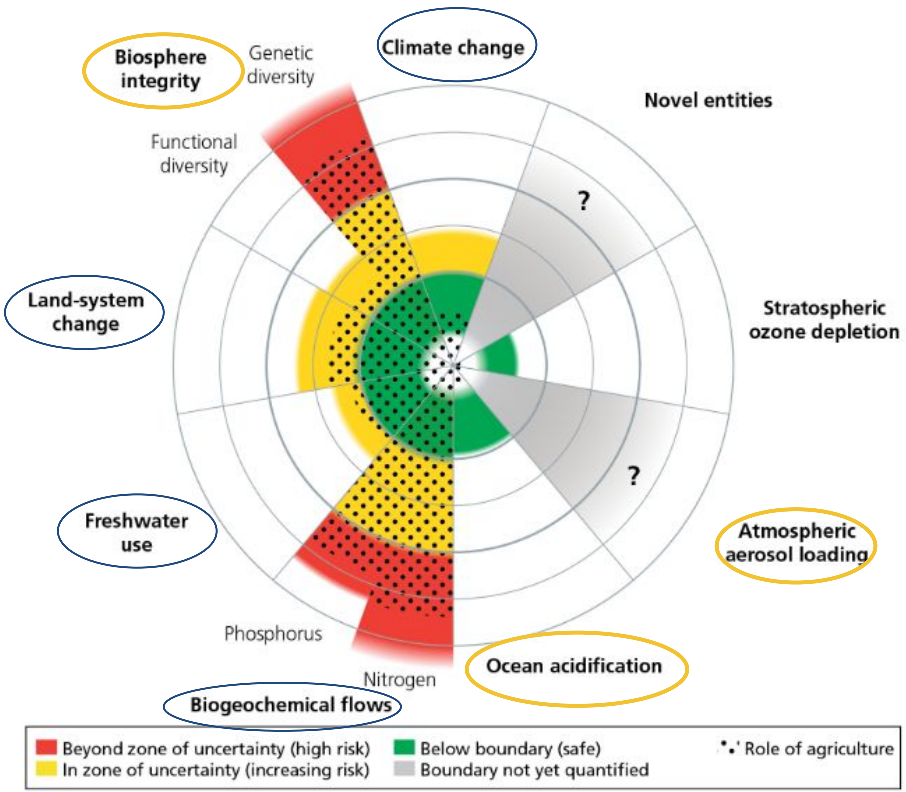
Lesk et al, submitted; Li et al 2019

Food Security and Environmental Goals

Breaking it down

- The lens of food security
- Climate impacts on food security
- **Agricultural impacts on other Earth systems**
- Needs for solution space

Agriculture impacts on Earth Systems and Services



A planetary boundaries approach allows us to consider the risks posed by agricultural production across a range of different Earth System components

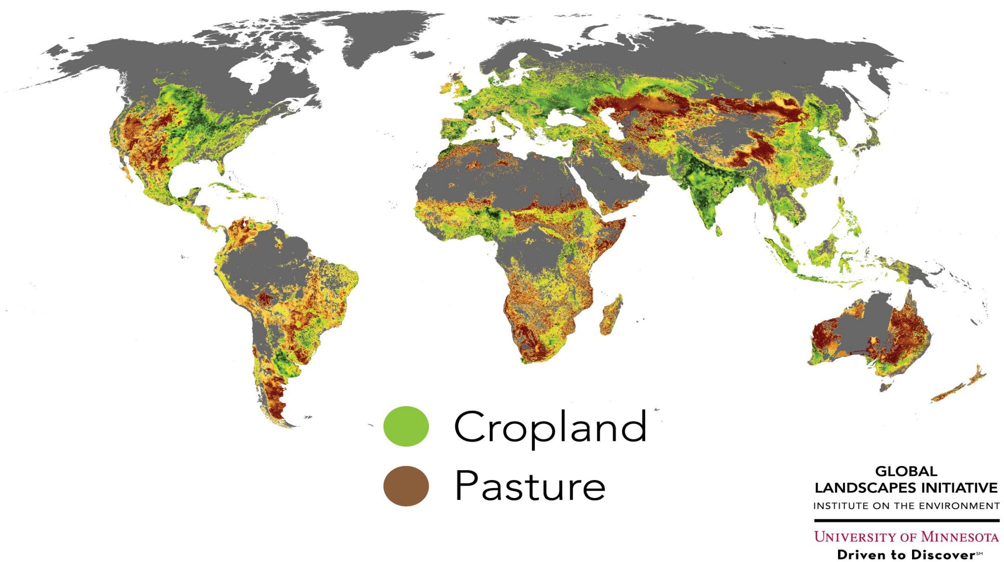
Model capacity is increasing to represent many of these system impacts in some form

Enables us to move beyond “carbon reductionism” when we consider the solution space

Connectivities to other Earth systems

Campbell et al 2017

Agriculture impacts on Earth Systems and Services



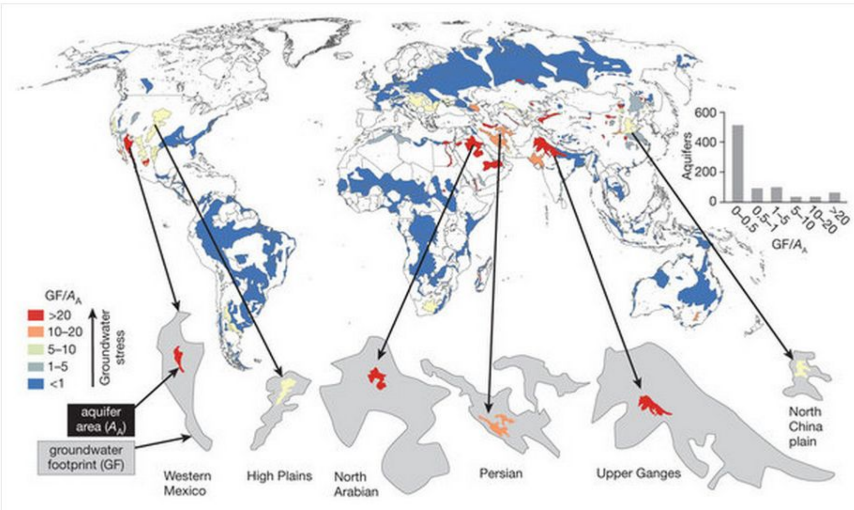
Land system change

Modeling community focus on LULCC; consider for different objectives (i.e. Half Earth or land sharing)

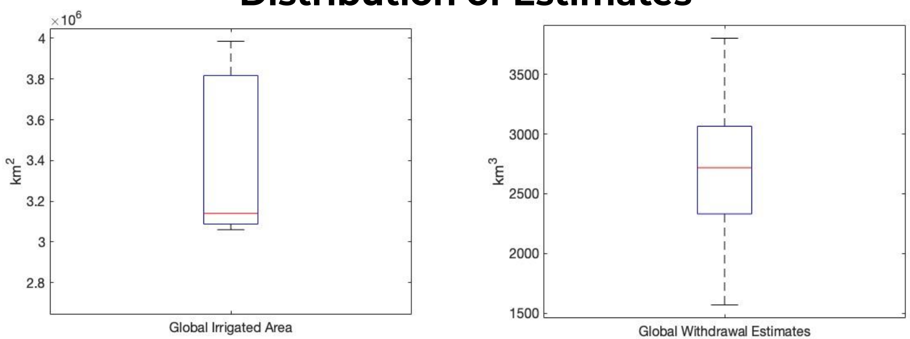
Harmonized protocols (e.g. LUMIP) enable more systematic investigations of the human land management forcing on Earth systems

Adequately representing many forms of land management (beyond land cover change) is a still a major area of model development

Agriculture impacts on Earth Systems and Services



Distribution of Estimates



Fresh water use

Models demonstrate irrigation-induced cooling; may also attenuate heat extremes

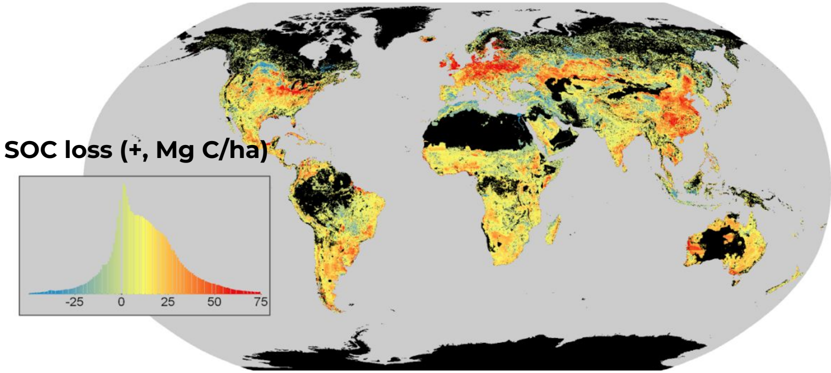
More uncertainty surrounding precipitation and humid heat impacts

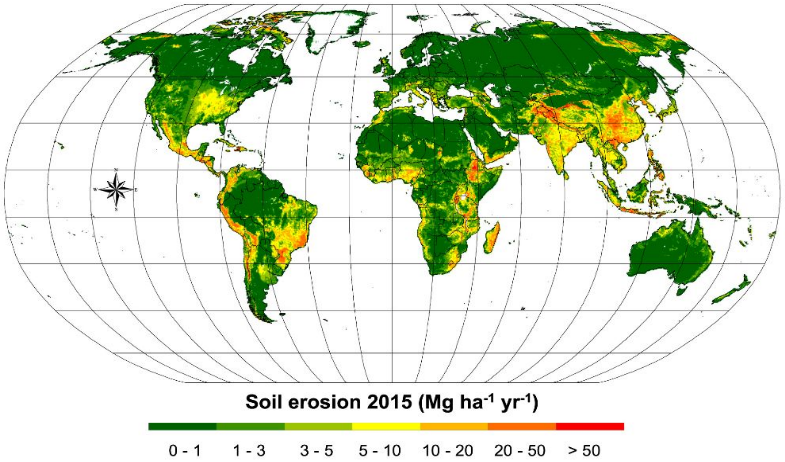
Still limitations in estimating non-renewable irrigation, irrigation limits, and water closure with irrigation (ongoing developments to include groundwater)

LUMIP also provided a protocol to assess irrigation impacts in land-only experiments

Gleeson et al 2012, McDermid et al, in prep

Agriculture impacts on Earth Systems and Services





Soil degradation

How do land management and climate change impact SOC and on what timescales?

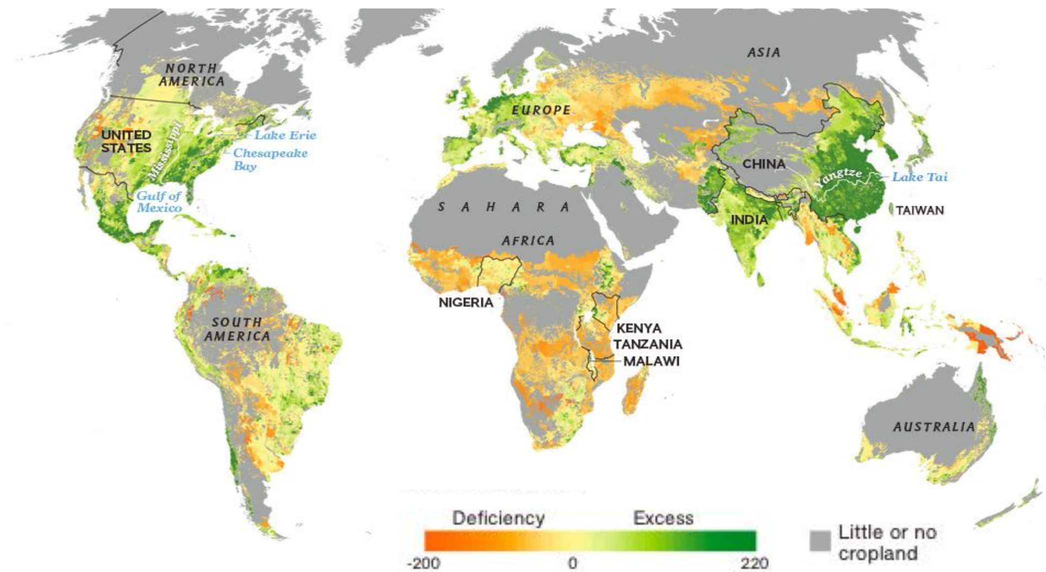
How do soil organic carbon changes impact key climate and ecosystem processes and services?

Nutrient availability in agroecosystems
Topsoil loss and soil "dust" emissions

A rapidly-developing space for agricultural C-sequestration, beyond above-ground terrestrial carbon stocks

Sanderman et al 2017; Borelli et al 2020

Agriculture impacts on Earth Systems and Services



Biogeochemical flows

Losses from agroecosystems into other parts of the Earth System, particularly coastal systems

Changes in C and N cycling across forms and species

Again, ramifications for meeting mitigation goals in agriculture, and for transitions towards improved and/or alternative management

Agriculture impacts on Earth Systems and Services

- Other dimensions that require exploration include interactions with:
  - (Conditions supporting) biodiversity (e.g. land sparing vs land sharing)
  - Atmospheric aerosols
  - Coastal and aquatic systems

- Counterfactual/baseline for comparison? Potential veg? Conventional ag? Will yield very different interpretation of results and assessing “benefits”/solution space

- What questions do we want to ask and what level of information/detail is required? Land management is ultimately embedded in social, political and economic systems whose uncertainties may supercede even the natural systems we attempt to represent.

UN FAO; Sustainable Development Goals

Goals for Lecture

- The lens of food security
- Climate impacts on food security
- Agricultural impacts on other Earth systems
- **Needs for solution space**

Needs to define solution space

			GHG emissions	Cropland use	Water use	Nitrogen application	Phosphorus application	Biodiversity loss
Food production boundary			5.0 (4.7–5.4)	13 (11.0–15.0)	2.5 (1.0–4.0)	90 (65.0–140.0)	8 (6.0–16.0)	10 (1–80)
Baseline in 2010			5.2	12.6	1.8	131.8	17.9	100–1000
Production (2050)	Waste (2050)	Diet (2050)						
BAU	Full waste	BAU	9.8	21.1	3.0	199.5	27.5	1,043
BAU	Full waste	Dietary shift	5.0	21.1	3.0	191.4	25.5	1,270
BAU	Halve waste	BAU	9.2	18.2	2.6	171.0	23.2	684
BAU	Halve waste	Dietary shift	4.5	18.1	2.6	162.6	21.2	885
PROD	Full waste	BAU	8.9	14.8	2.2	187.3	25.5	206
PROD	Full waste	Dietary shift	4.5	14.8	2.2	179.5	24.1	351
PROD	Halve waste	BAU	8.3	12.7	1.9	160.1	21.5	50
PROD	Halve waste	Dietary shift	4.1	12.7	1.9	151.7	20.0	102
PROD+	Full waste	BAU	8.7	13.1	2.2	147.6	16.5	37
PROD+	Full waste	Dietary shift	4.4	12.8	2.1	140.8	15.4	34
PROD+	Halve waste	BAU	8.1	11.3	1.9	128.2	14.2	21
PROD+	Halve waste	Dietary shift	**4.0**	**11.0**	**1.9**	**121.3**	**13.1**	**19**

The EAT-Lancet Commission on Food, Planet, Health

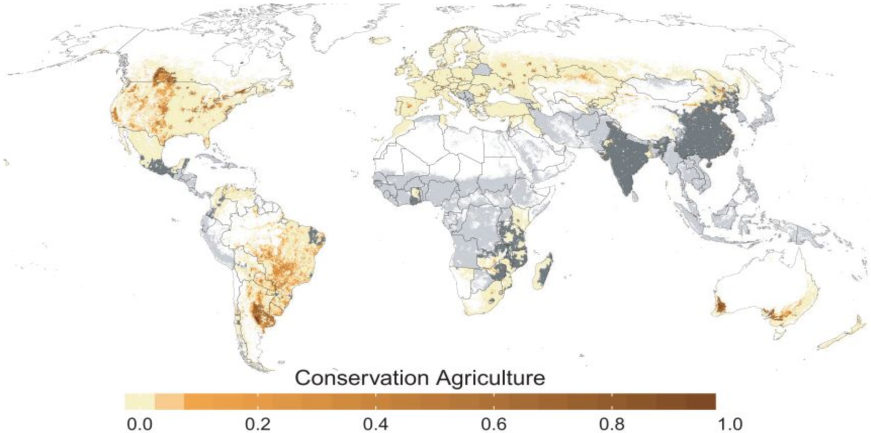
Can we feed a future population of 10 billion people a healthy diet within planetary boundaries?

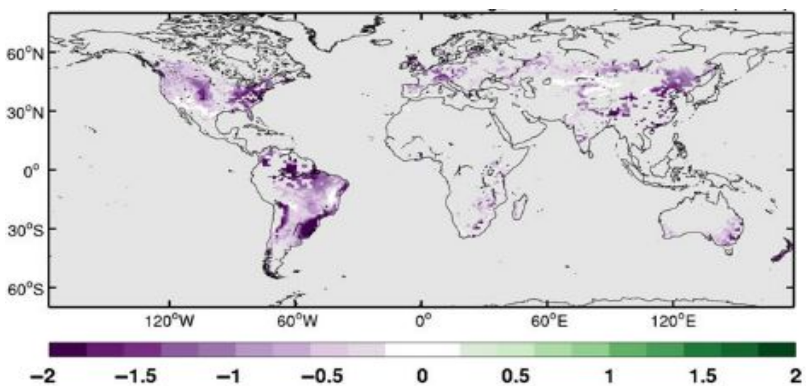
Improve production*, shift diets*, and halve waste to sustainably nourish 9-10B by 2050

*Entry points for land modeling

Willet et al 2019; Springmann et al 2018

Needs to define solution space





Improved Production

(How) can alternative production contribute to food security. . .

AND reducing agriculture's environmental footprint?

IF implemented alongside reducing waste and shifting diets

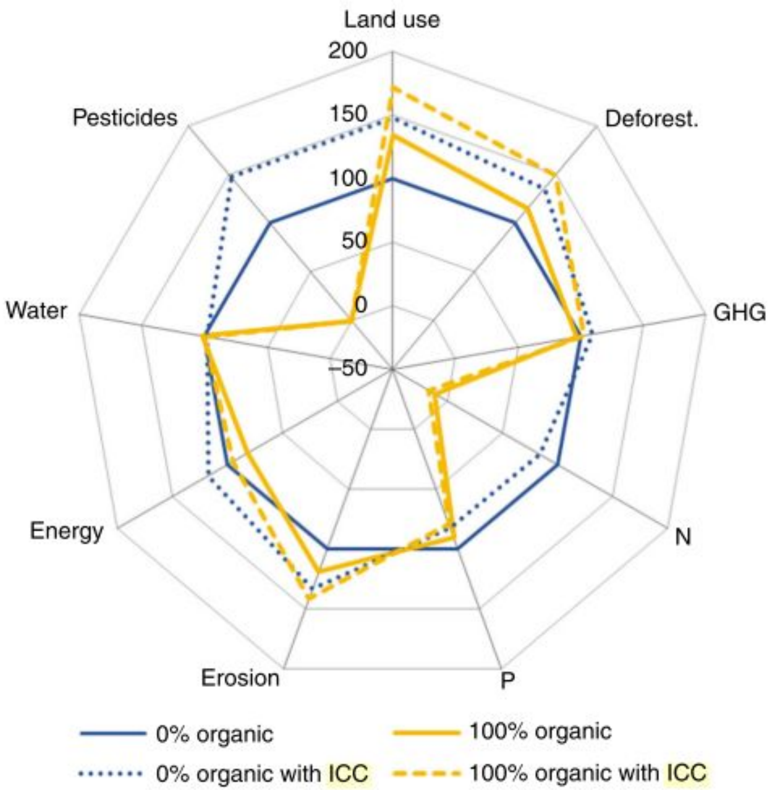
More work needed, however, to assess production potentials - and of what crops? - under changing climate/environmental conditions

Purple shows both cooler and wetter surface conditions

Prestele et al 2018; Hirsch et al 2018

Needs to define solution space

Organic vs Conventional in 2050



Improved Production

(How) can alternative production contribute to food security. . .

AND reducing agriculture's environmental footprint?

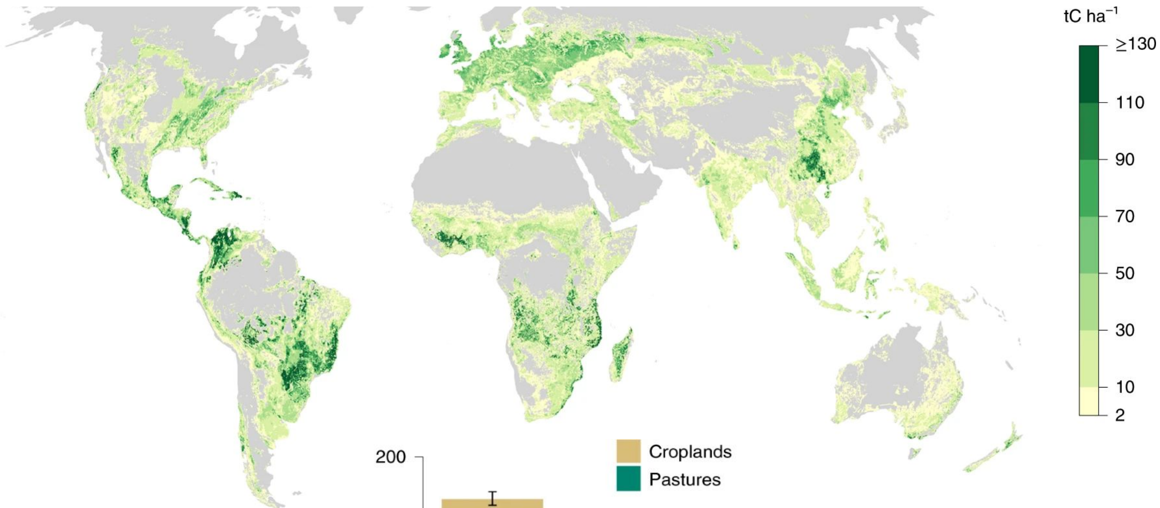
IF implemented alongside reducing waste and shifting diets

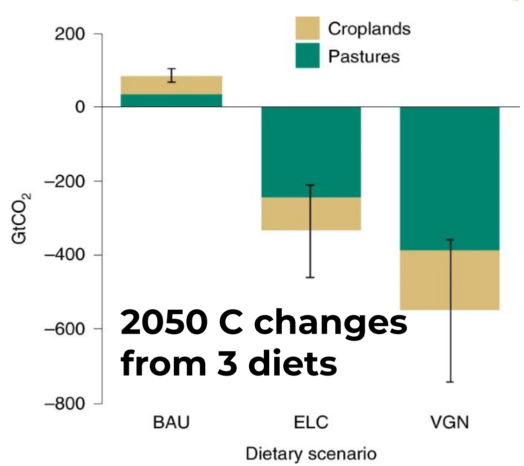
More work needed, however, to assess production potentials - and of what crops? - under changing climate/environmental conditions

Mueller et al 2017

Needs to define solution space

C potentials in present-day animal ag lands





2050 C changes from 3 diets

Shifting Diets/Production

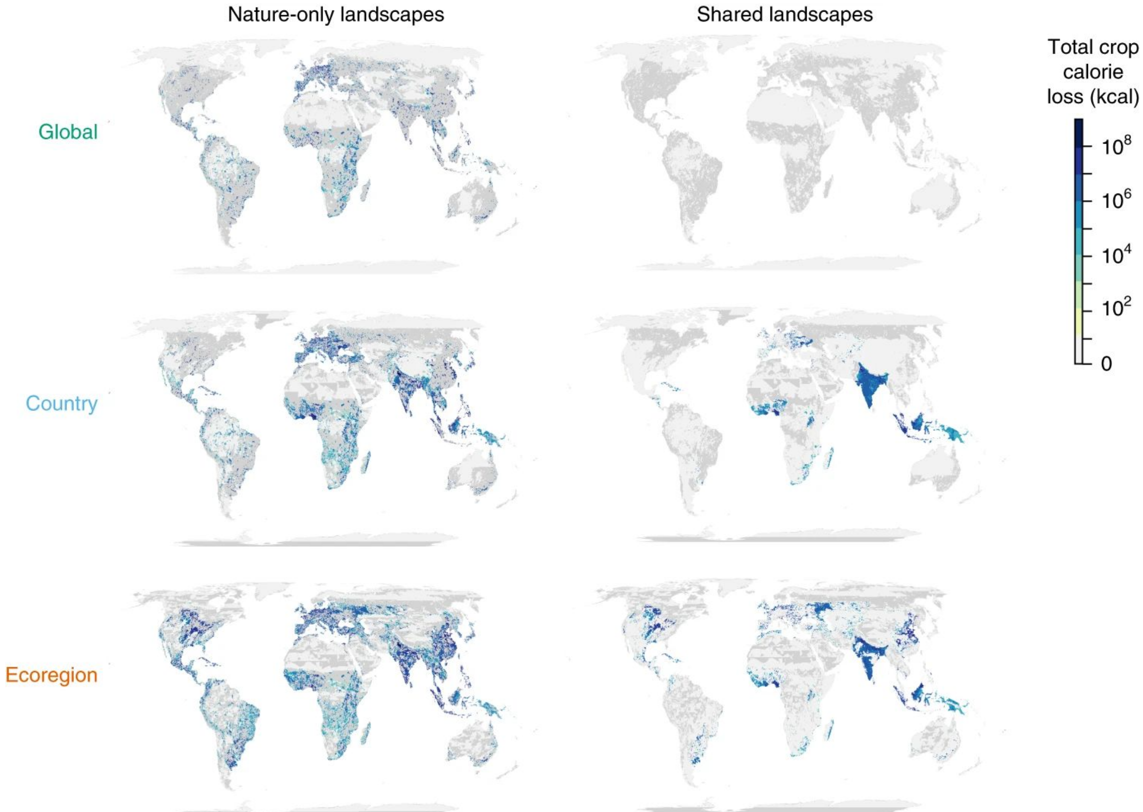
How do dietary changes (one way or another) impact land cover change, carbon, and water?

What are co-benefits and trade-offs, beyond C sequestration?

Hayek et al 2020

Needs to define solution space

Calorie losses under Half-Earth scenario



Balancing production and biodiversity

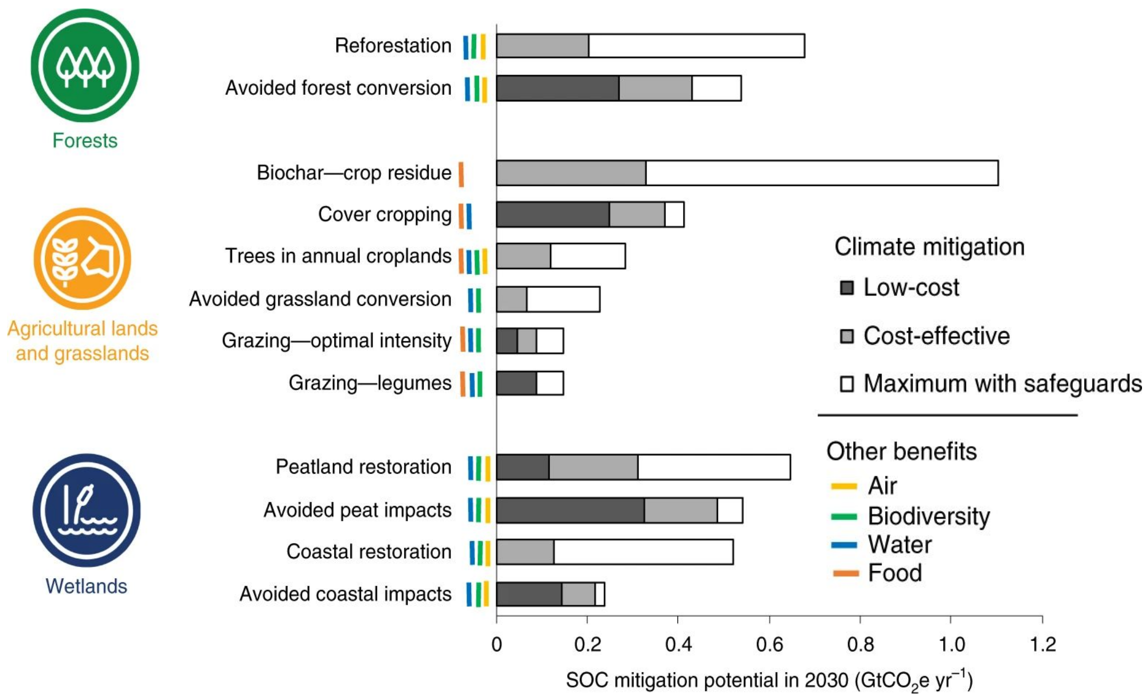
How will biodiversity and land conservation strategies impact food production?

Dietary trends will also matter for the impact and implementation of these scenarios

Mehrabi et al 2018

Needs to define solution space

Mitigation and Adaptation in Agriculture



There is an increasing push toward building agricultural SOC stocks for climate mitigation

Need further development, process-level constraints, and management representations in models for SOC investigation

Also need full-cost accounting: agroecosystem emissions and productivity alongside measures of SOC

Bossio et al 2020

Needs to defined solution space

- Look beyond SSP scenarios to consider co-benefits and trade-offs with respect to diet/nutrition, (conditions for) biodiversity, and other planetary boundaries

- Coupled modeling with more comprehensive/improved land surface representation will provide better insight into important climate <-> agroecosystem feedbacks that are currently lacking in discussion of "potentials"

- Assess efficiencies/intensities and co-benefits/tradeoffs by service to food security

UN FAO; Sustainable Development Goals

Thank You

The Brave Commander freighter departed from the Ukrainian port of Yuzhne, east of Odesa | Oleksandr Gimanov/AFP via Getty Images

- What data/model developments are required to assess the agricultural adaptation and mitigation space?
- What is needed to expand "mitigation" purview beyond carbon?
- How does taking a normative perspective - foregrounding food security and ecosystem services - support novel and impactful research questions?

References

Bradford et al (2017) Future soil moisture and temperature extremes imply expanding suitability for rainfed agriculture in temperate drylands. https://www.nature.com/articles/s41598-017-13165-x

Sloat et al (2020) Climate adaptation by crop migration. https://www.nature.com/articles/s41467-020-15076-4

Toreti et al 2020 Narrowing uncertainties in the effects of elevated CO2 on crops https://www.nature.com/articles/s43016-020-00195-4

Alexander, P., Rounsevell, M.D.A., Dislich, C., Dodson, J.R., Engström, K., Moran, D., 2015. Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy. Glob. Environ. Chang. 35, 138–147. https://doi.org/10.1016/J.GLOENVCHA.2015.08.011

Cassidy, E.S., West, P.C., Gerber, J.S., Foley, J.A., 2013. Redefining agricultural yields : from tonnes to people nourished per hectare 034015. https://doi.org/10.1088/1748-9326/8/3/034015

DeFries, R., Mondal, P., Singh, D., Agrawal, I., Fanzo, J., Remans, R., Wood, S., 2016. Synergies and trade-offs for sustainable agriculture: Nutritional yields and climate-resilience for cereal crops in Central India. Glob. Food Sec. 11, 44–53. https://doi.org/10.1016/J.GFS.2016.07.001

Deryng, D., Elliott, J., Folberth, C., Müller, C., Pugh, T.A.M., Boote, K.J., Conway, D., Ruane, A.C., Gerten, D., Jones, J.W., Khabarov, N., Olin, S., Schaphoff, S., Schmid, E., Yang, H., Rosenzweig, C., 2016. Regional disparities in the beneficial effects of rising CO2 concentrations on crop water productivity. Nat. Clim. Chang. https://doi.org/10.1038/nclimate2995

Deutsch, C.A., Tewksbury, J.J., Tigchelaar, M., Battisti, D.S., Merrill, S.C., Huey, R.B., Naylor, R.L., 2018. Increase in crop losses to insect pests in a warming climate. Science (80-.). 361, 916–919. https://doi.org/10.1126/SCIENCE.AAT3466

Emberson, L.D., Pleijel, H., Ainsworth, E.A., van den Berg, M., Ren, W., Osborne, S., Mills, G., Pandey, D., Dentener, F., Büker, P., Ewert, F., Koeble, R., Van Dingenen, R., 2018. Ozone effects on crops and consideration in crop models. Eur. J. Agron. 100, 19–34. https://doi.org/10.1016/J.EJA.2018.06.002

Hasegawa, T., Havlík, P., Frank, S., Palazzo, A., Valin, H., 2019. Tackling food consumption inequality to fight hunger without pressuring the environment. Nat. Sustain. 2, 826–833. https://doi.org/10.1038/s41893-019-0371-6

References con’t

Herrero, M., Thornton, P.K., Power, B., Bogard, J.R., Remans, R., Fritz, S., Gerber, J.S., Nelson, G., See, L., Waha, K., Watson, R.A., West, P.C., Samberg, L.H., van de Steeg, J., Stephenson, E., van Wijk, M., Havlík, P., 2017. Farming and the geography of nutrient production for human use: a transdisciplinary analysis. Lancet Planet. Heal. 1, e33–e42. https://doi.org/10.1016/S2542-5196(17)30007-4

Homann-Kee Tui, S., Valbuena, D., Masikati, P., Descheemaeker, K., Nyamangara, J., Claessens, L., Erenstein, O., van Rooyen, A., Nkomboni, D., 2013. Economic trade-offs of biomass use in crop-livestock systems: Exploring more sustainable options in semi-arid Zimbabwe. Agric. Syst. https://doi.org/10.1016/j.agsy.2014.06.009

Li, Y., Guan, K., Schnitkey, G.D., DeLucia, E., Peng, B., 2019. Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States. Glob. Chang. Biol. 25, 2325–2337. https://doi.org/10.1111/gcb.14628

Mueller, C., Elliott, J., Chryssanthacopoulos, J., Arneth, A., Balkovic, J., Ciais, P., Deryng, D., Folberth, C., Glotter, M., Hoek, S., Iizumi, T., Izaurralde, R.C., Jones, C., Khabarov, N., Lawrence, P., Liu, W., Olin, S., Pugh, T.A.M., Ray, D.K., Reddy, A., Rosenzweig, C., Ruane, A.C., Sakurai, G., Schmid, E., Skalsky, R., Song, C.X., Wang, X., de Wit, A., Yang, H., 2017. Global gridded crop model evaluation: benchmarking, skills, deficiencies and implications. Geosci. Model Dev. 10, 1403–1422. https://doi.org/10.5194/gmd-10-1403-2017

Muller, A., Schader, C., El-Hage Scialabba, N., Brüggemann, J., Isensee, A., Erb, K.-H., Smith, P., Klocke, P., Leiber, F., Stolze, M., Niggli, U., 2017. Strategies for feeding the world more sustainably with organic agriculture. Nat. Commun. 8, 1290. https://doi.org/10.1038/s41467-017-01410-w

Myers, S.S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A.D.B., Bloom, A.J., Carlisle, E., Dietterich, L.H., Fitzgerald, G., Hasegawa, T., Holbrook, N.M., Nelson, R.L., Ottman, M.J., Raboy, V., Sakai, H., Sartor, K. a., Schwartz, J., Seneweera, S., Tausz, M., Usui, Y., 2014. Increasing CO2 threatens human nutrition. Nature 510, 139–142. https://doi.org/10.1038/nature13179

Prestele, R., Hirsch, A.L., Davin, E.L., Seneviratne, S.I., Verburg, P.H., 2018. A spatially explicit representation of conservation agriculture for application in global change studies. Glob. Chang. Biol. 24, 4038–4053. https://doi.org/10.1111/gcb.14307

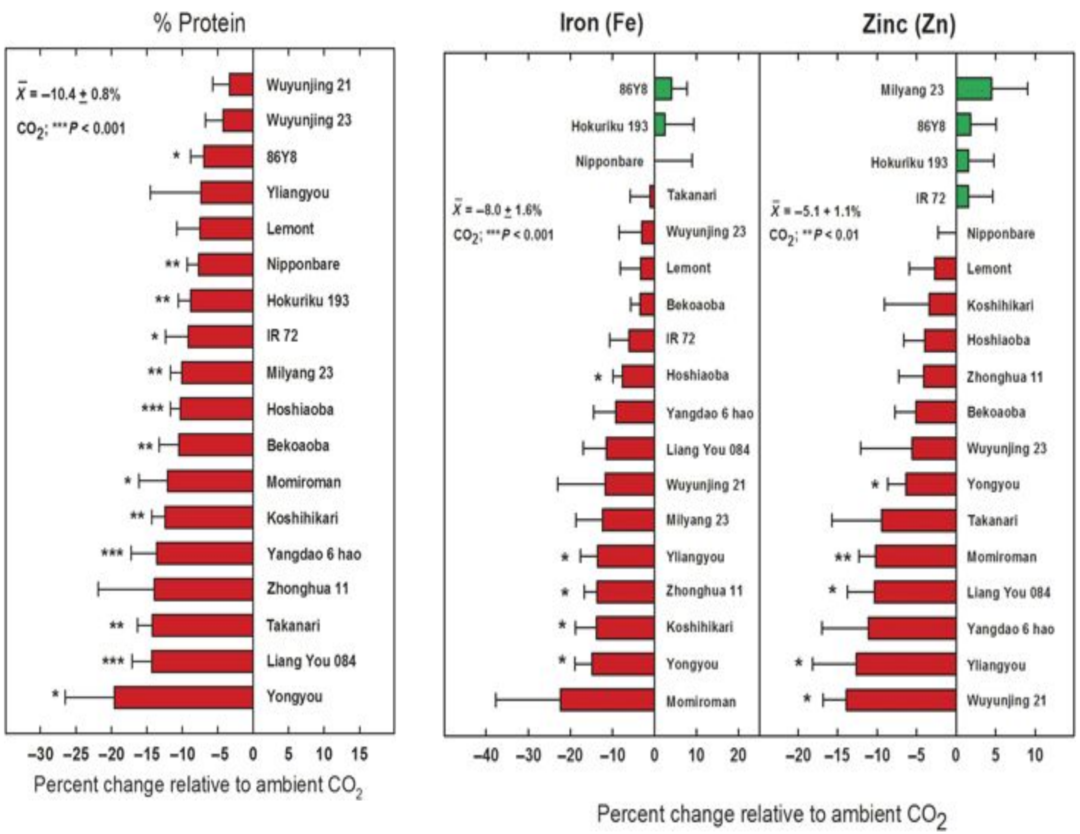
Springmann, M., Clark, M., Mason-D’Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., de Vries, W., Vermeulen, S.J., Herrero, M., Carlson, K.M., Jonell, M., Troell, M., DeClerck, F., Gordon, L.J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., Godfray, H.C.J., Tilman, D., Rockström, J., Willett, W., 2018. Options for keeping the food system within environmental limits. Nature 1. https://doi.org/10.1038/s41586-018-0594-0

References con’t

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Majele Sibanda, L., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Srinath Reddy, K., Narain, S., Nishtar, S., L Murray, C.J., 2019. The Lancet Commissions Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems Executive summary. https://doi.org/10.1016/S0140-6736(18)31788-4

Zhu, C., Kobayashi, K., Loladze, I., Zhu, J., Jiang, Q., Xu, X., Liu, G., Seneweera, S., Ebi, K.L., Drewnowski, A., Fukagawa, N.K., Ziska, L.H., 2018. Carbon dioxide (CO 2) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries. Sci. Adv. 4, 8. https://doi.org/10.1126/sciadv.aaq1012

Climate Change Impacts on Agriculture



Some Key Uncertainties: CO2 fertilization

Yield % change resulting from inclusion of BAU 2050 [CO2] fertilization effects

Percentage change in nutrients at elevated [CO2] relative to ambient [CO2]

Zhu et al 2018