

Global Food Security

- Ensuring sustainable food production at local to global scales

**Beauty and the beast:
Achilles heels, ecological intensification,
and parsimonious big data**

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Humanity's greatest challenge

- **Creating sufficient wealth to achieve zero population growth by mid-century, and an orderly, gradual decline thereafter to a sustainable equilibrium level**
- **Requirements to reach this goal for a peak population of 10-11 billion:**
 - **Universal education**
 - **Equitable access to resources, good governance**
 - **Adequate energy and food supply at reasonable cost**
 - **Environmentally sustainable means of production**
 - **Conserving adequate remnant “natural ecosystems”**

Here and throughout this talk, “food security”, or “adequate food supply”, refers to adequate calories, protein, and all essential nutrients, micro-nutrients and vitamins.....

Long-Term Trends Are Promising!

- Enormous reduction in proportion of poor and hungry
- Rising incomes, rapidly growing global middle class
- Steadily declining population growth rate
- Increasing longevity from improved health & nutrition

Looming Challenges

- Agricultural time bomb: clearing land for crop production
- Degradation of soil quality on existing agricultural land
- Global food supply on a razors edge:
 - Greater variability from climate change, soil degradation
 - Increasing number of countries that can afford to bid up food prices when supply is short

More Good News!

Resounding **consensus** on major “qualitative” issues

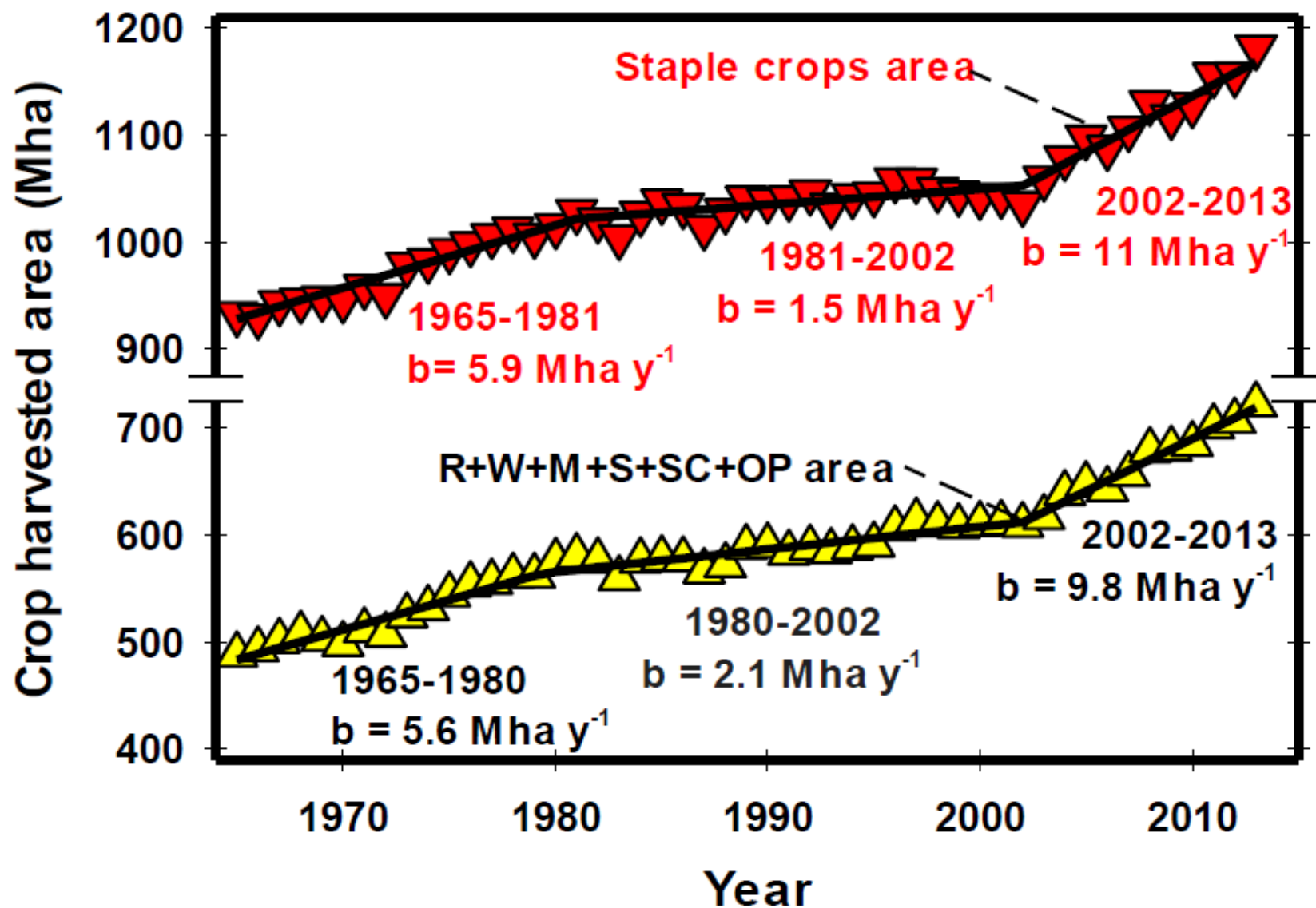
- Planet earth must be food self-sufficient
- Affordable, accessible food supply is essential for continued reductions in poverty and hunger
- Land use requirements for agriculture, and environmental impacts from food production, will have enormous consequences for biodiversity, climate change, and therefore.....
- Minimizing expansion of crop and pasture land to avoid further conversion of natural ecosystems

Despite consensus on qualitative issues, enormous disagreement on quantitative issues

- How much food will be required?
- How best to produce it (organic, conventional, degree of crop diversity, local vs global,.....)?
- Where to produce it?
- All of the above underpin **self-sufficiency** issues: where, what, how.....

Given the race against time, urgent need to reach consensus on these issues or risk “ad hoc” short-term solutions that are not sustainable

Ad hoc solution---Agricultural time bomb since 2002



Modified from: Grassini et al. 2013. Nature Comm.



Urban-industrial expansion “tsunami” onto prime farmland at the periphery of Kunming (+6 million), the capital of Yunnan Province, China,

28-29 Ja 2016

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Photo: K.G. Cassman

Unsustainable crop production on marginal land by poor farm families without other options



28-29 Jan, 2016

FarmLink Visit

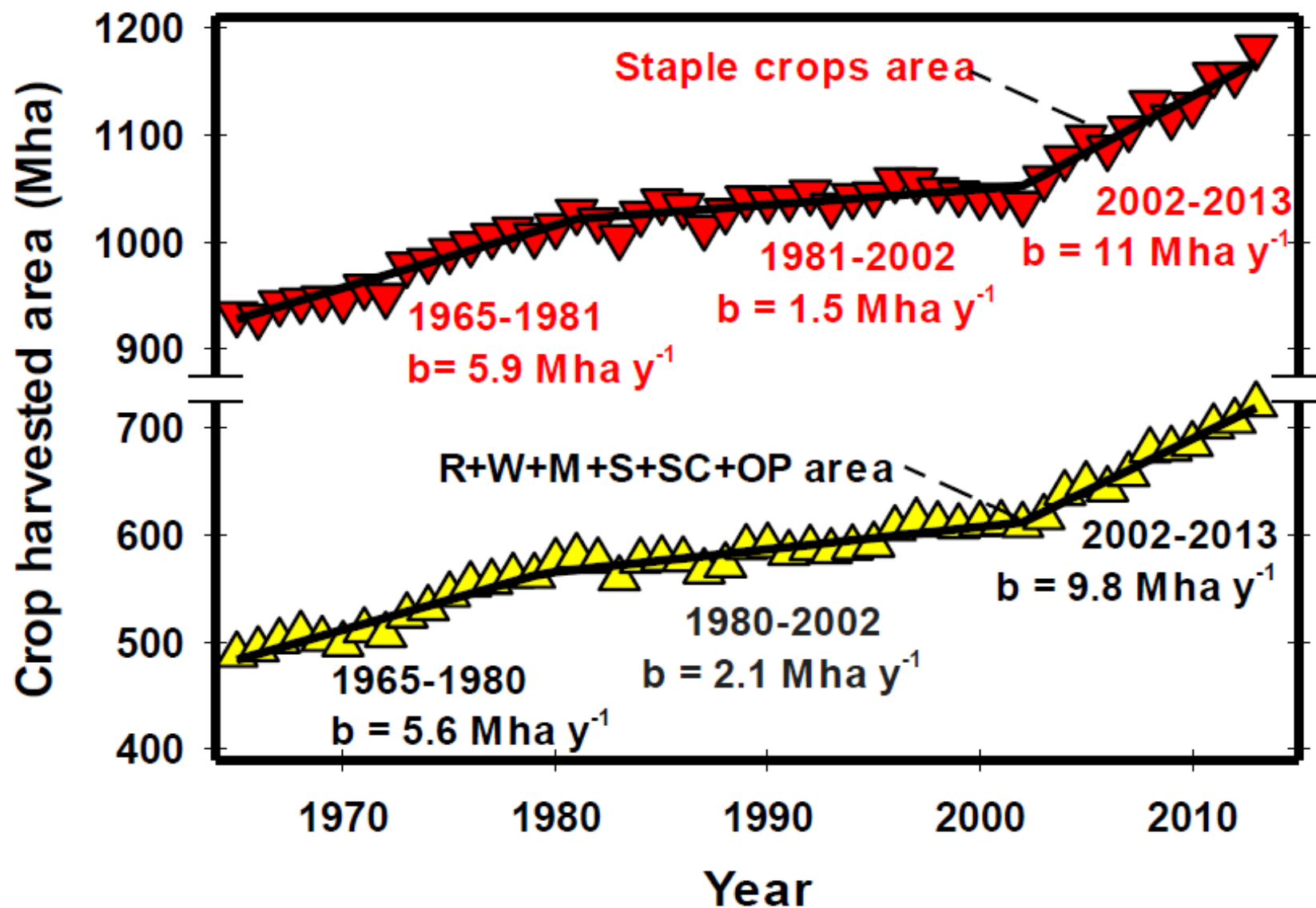
Photo: K.G. Cassman

Clearing virgin rain forest (Brazil): powerful +feedback to GHG emissions



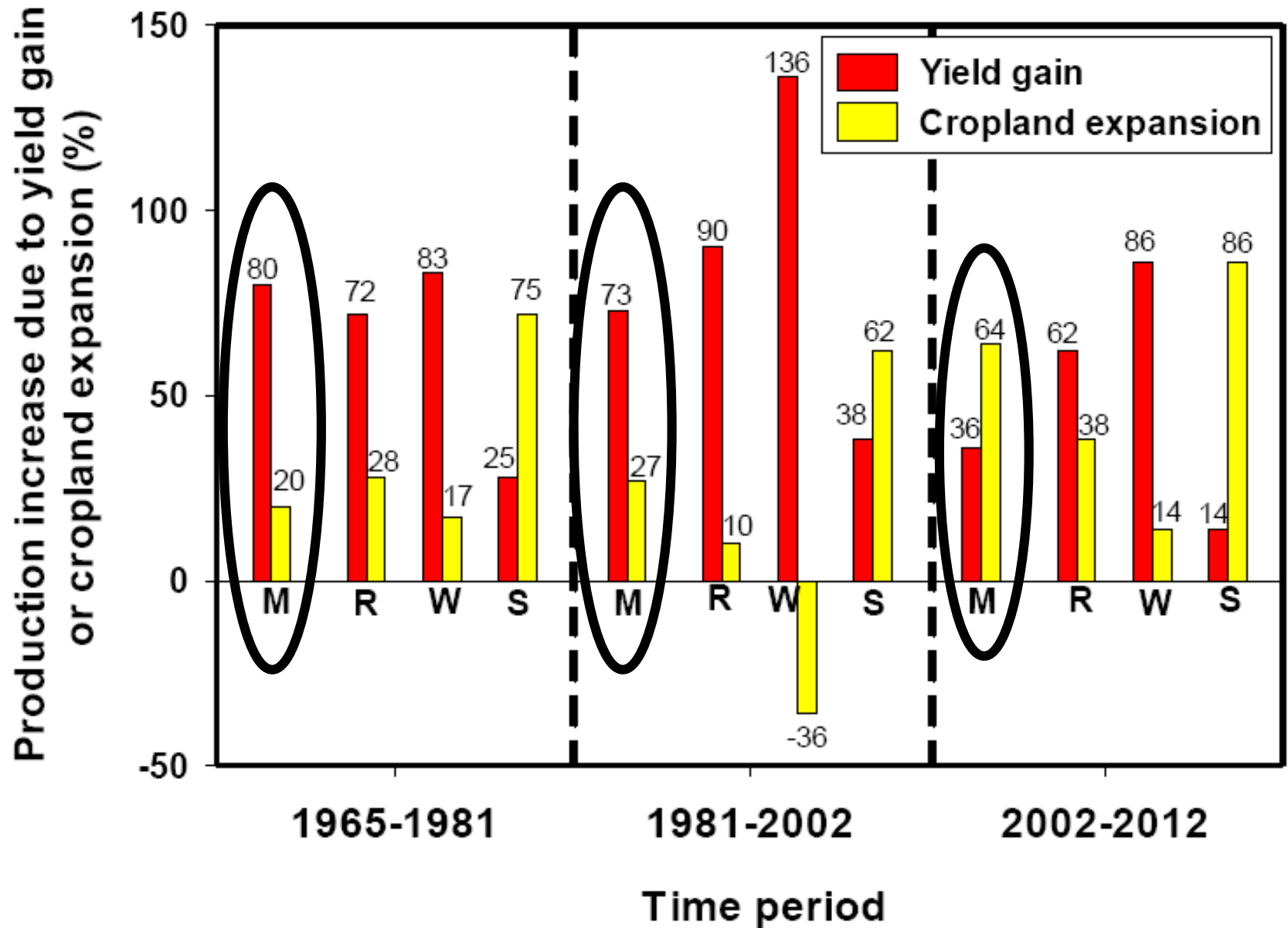
Photo: K.G .Cassma

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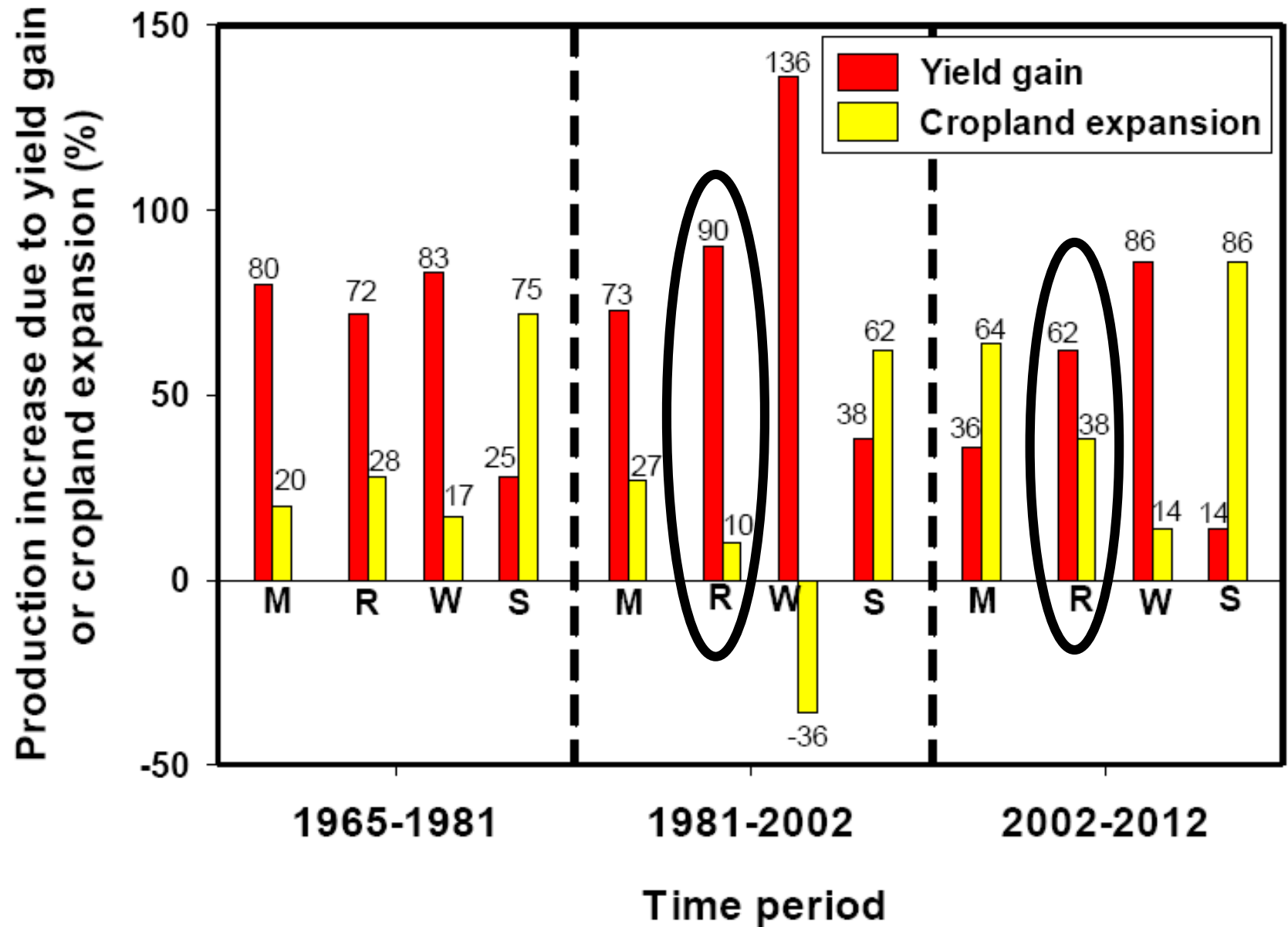


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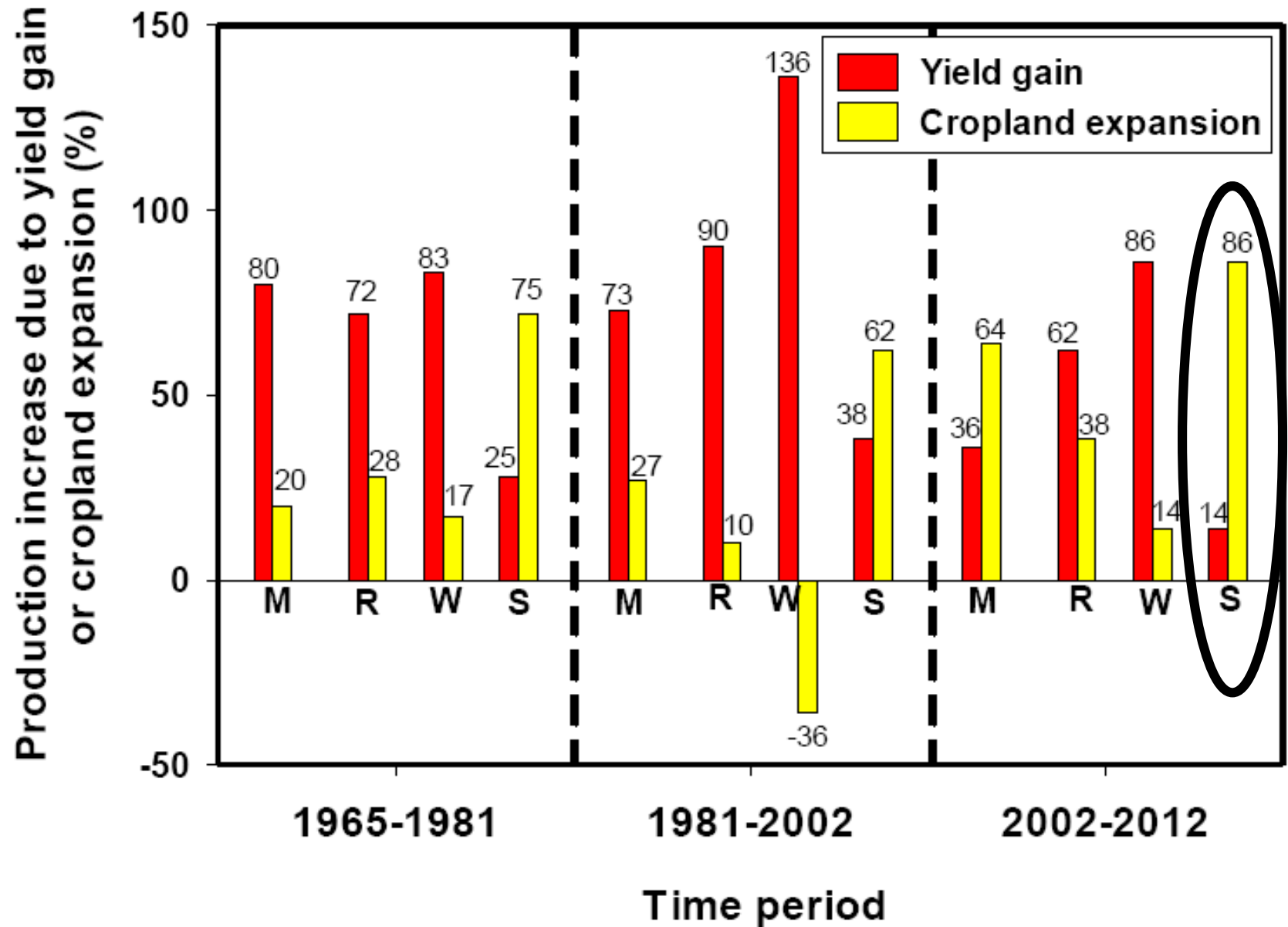
Yield gain versus cropland area expansion



Yield gain versus cropland area expansion

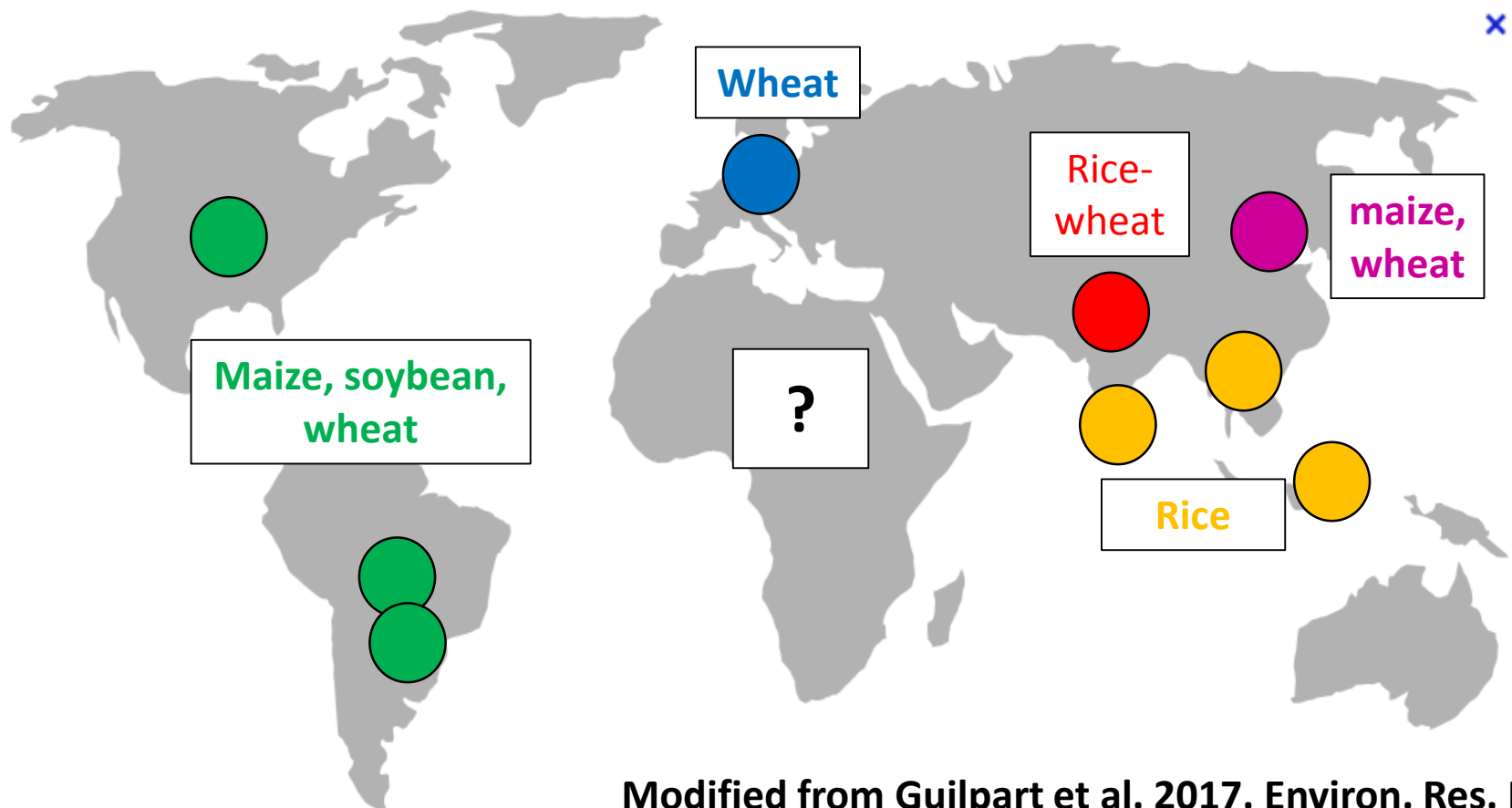


Yield gain versus cropland area expansion



Critical role of breadbaskets

A **breadbasket** is an area that produces a large surplus of one or several agricultural commodities (typically cereals and oilseed crops) so that it not only meets the local demand but can consistently contribute to food supply at a larger scale. Requires good soils, reliable climate, and in some cases, irrigation.



Common features of world's breadbasket systems

- **Average farm yields are approaching the attainable yield ceiling (75-85% of biophysical yield potential) although there is still substantial potential to further increase yields**
- **Three seemingly inherent Achilles Heels:**
 - **Soil quality degradation**
 - **Nitrogen pollution**
 - **Pesticide treadmill (increasing disease, insect and weed resistance)**

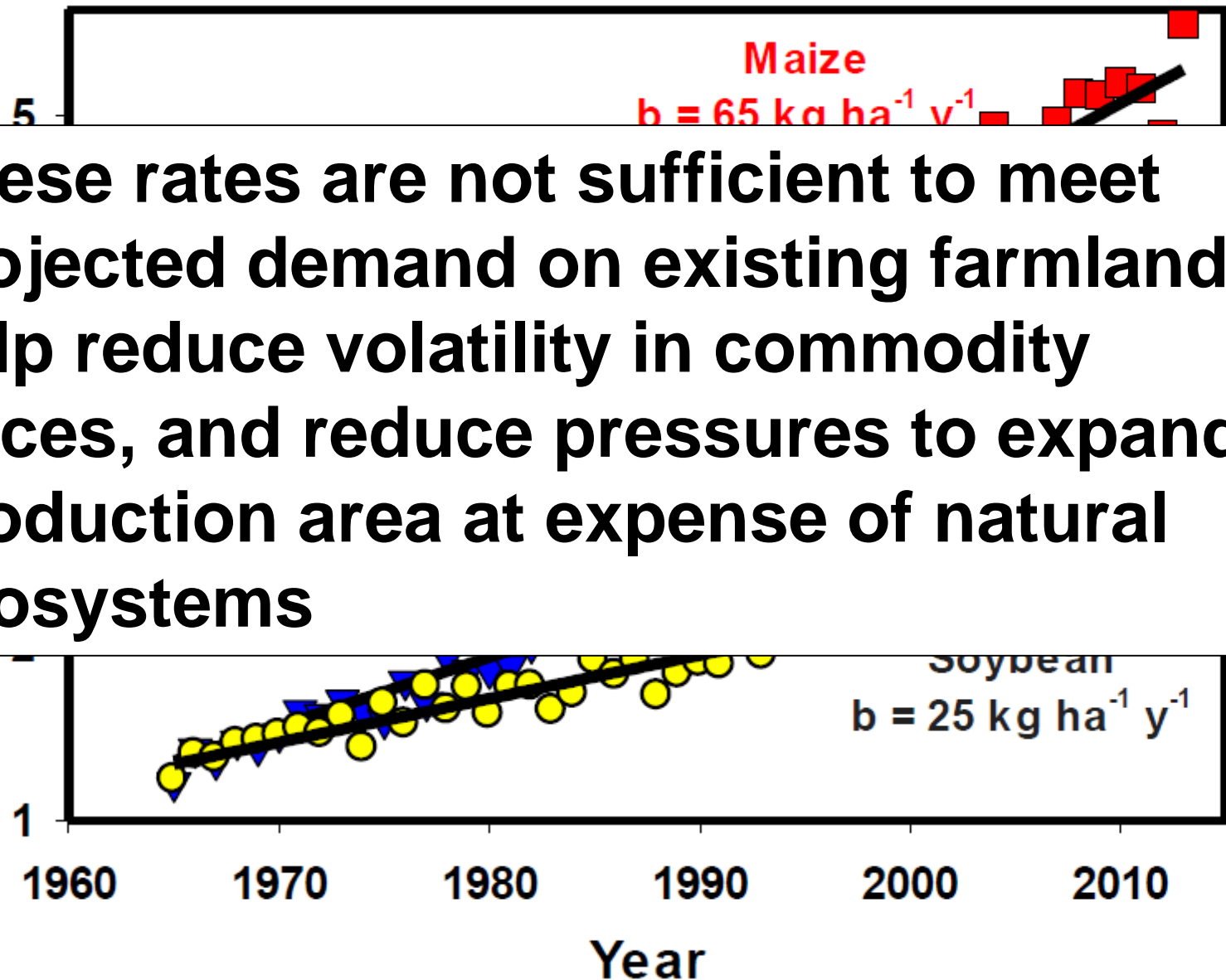
ECOLOGICAL INTENSIFICATION: the path forward for major Breadbaskets

- ***Consistently producing crop yields that are 75-85% of yield potential***
- ***Maintain or improve soil quality***
- ***Reduce negative environmental impacts below critical thresholds***
 - Water quality, wildlife, biodiversity, global warming potential
- ***Substantially increase input use efficiency***
 - Nutrients, water, net energy yield, reduced pesticide use
- ***Necessary but not sufficient.....***

Modified from: Cassman KG. 1999. Proc. Natl. Acad. Sci. (USA) 96: 5952-5959

Big Picture: Slowing relative rate of yield increase

These rates are not sufficient to meet projected demand on existing farmland, help reduce volatility in commodity prices, and reduce pressures to expand production area at expense of natural ecosystems



The Challenges

- How to substantially **accelerate** rate of gain in crop yields globally while also achieving ecological intensification?
 - “quantum-leap” genetic gains on the horizon ***unlikely***
 - Must go beyond traditional agronomic field research model
- Requires harnessing the power of farmer-reported data, coupled with good quality, high spatial resolution data on soils and weather (long-term, current, forecast)
- A robust spatial framework to support more effective and efficient technology transfer
- Establishing appropriate metrics and benchmarks for monitoring progress, e.g. WUE, NUE, and environmental quality thresholds

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The End of Traditional Agronomy?

- Based on field experiments evaluating 2-3 management factors and Fisherian statistics to identify “significant” treatment effects
 - Example: 4 nitrogen management approaches, 3 planting dates, and 3 crop varieties (36 treatments, replicated a minimum of times, **which gives 108 total treatment plots**)
 - Established at several locations over several years to capture impact of soil types and weather variation
- But ecological intensification must optimize 10-20 factors all at once, and the performance of each factor is “interactive” (i.e depends on how other factors are done)
 - Crop rotation, variety selection, tillage method, sowing date, seeding rate, weed/insect/disease management tactics, fertilizer rate, timing formulation, placement, Etc...

Establishing a robust spatial framework for TECHNOLOGY EXTRAPOLATION DOMAINS (TEDs)


- TED definition: A spatial unit within which a particular crop or soil management technology (broad sense, including rotation, cropping patterns, management of soil biology) would be expected to perform similarly
- Also called a “recommendation space”
- The TED framework of the Global Yield Gap Atlas (GYGA, www.yieldgap.org) combines the **GYGA climate zones** with **plant available water holding capacity in the rootable soil depth** as the smallest spatial unit
- The “Goldilocks Challenge) not too fine, not too coarse.....

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LETTER

Beyond the plot: technology extrapolation domains for scaling out agronomic science

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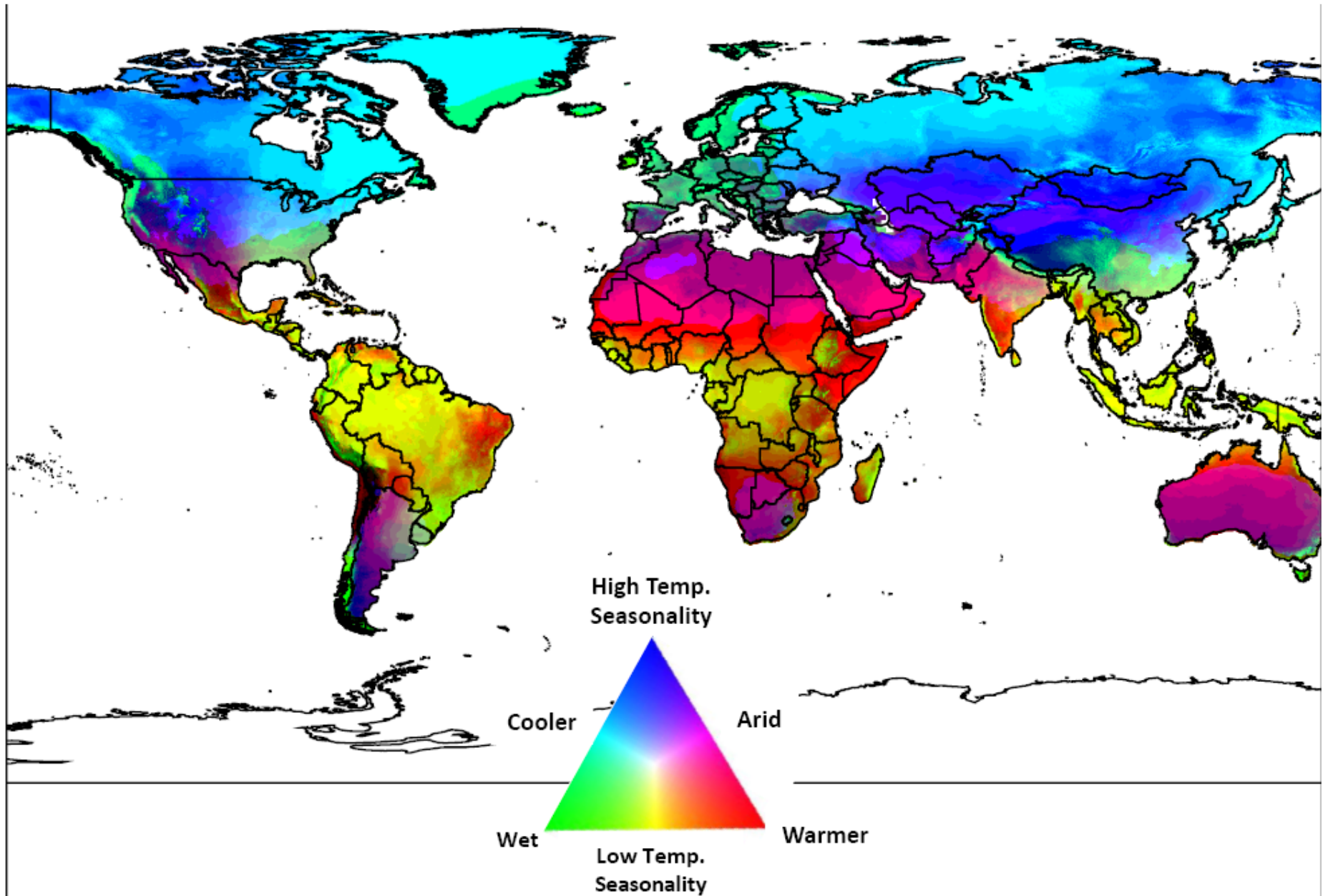
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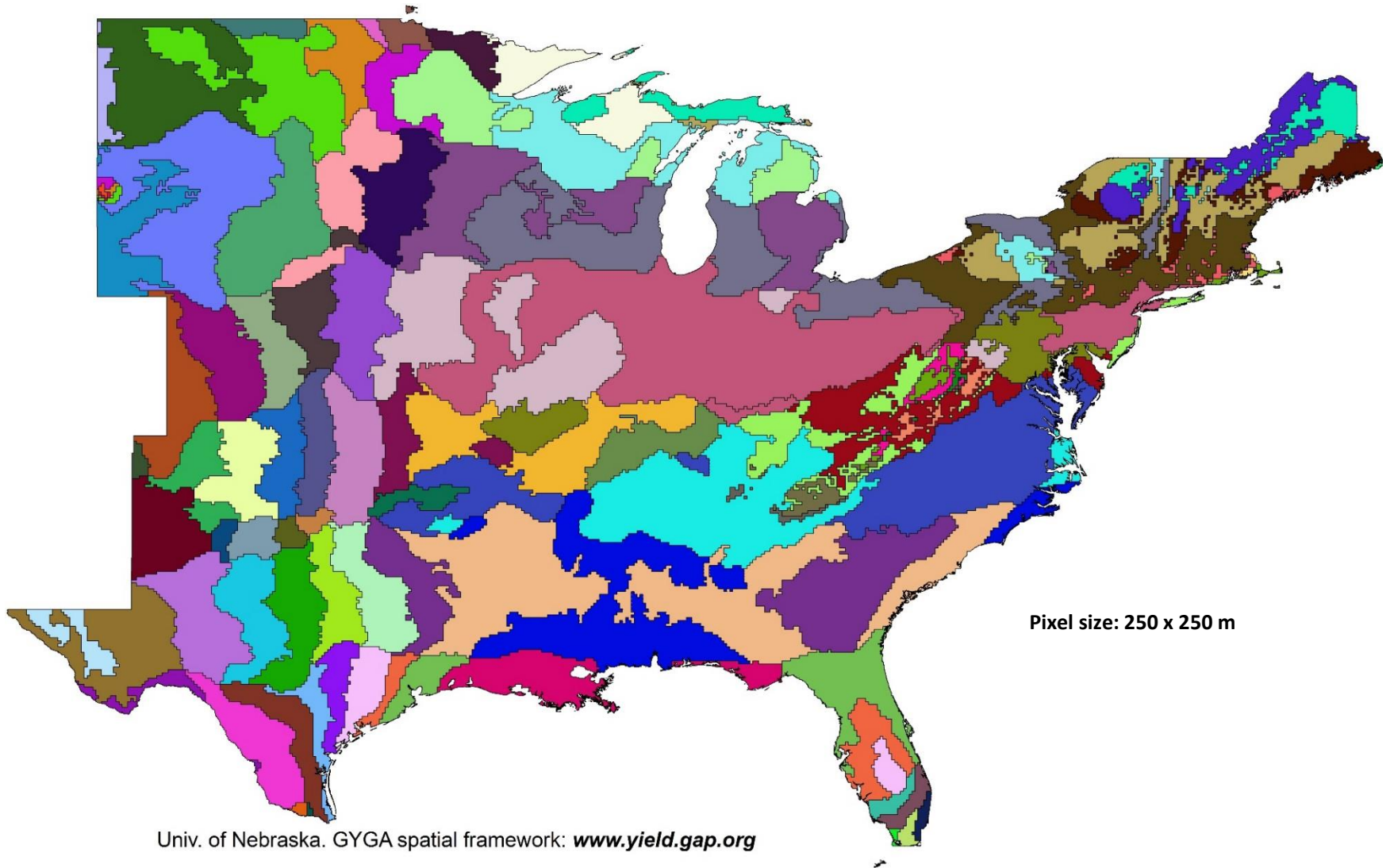
⁶ Author to whom any correspondence should be addressed.

Abstract quote: Here we develop a global spatial framework to delineate “**technology extrapolation domains**” based on key climate and soil factors that govern crops yields and yield stability in rainfed crop production.....

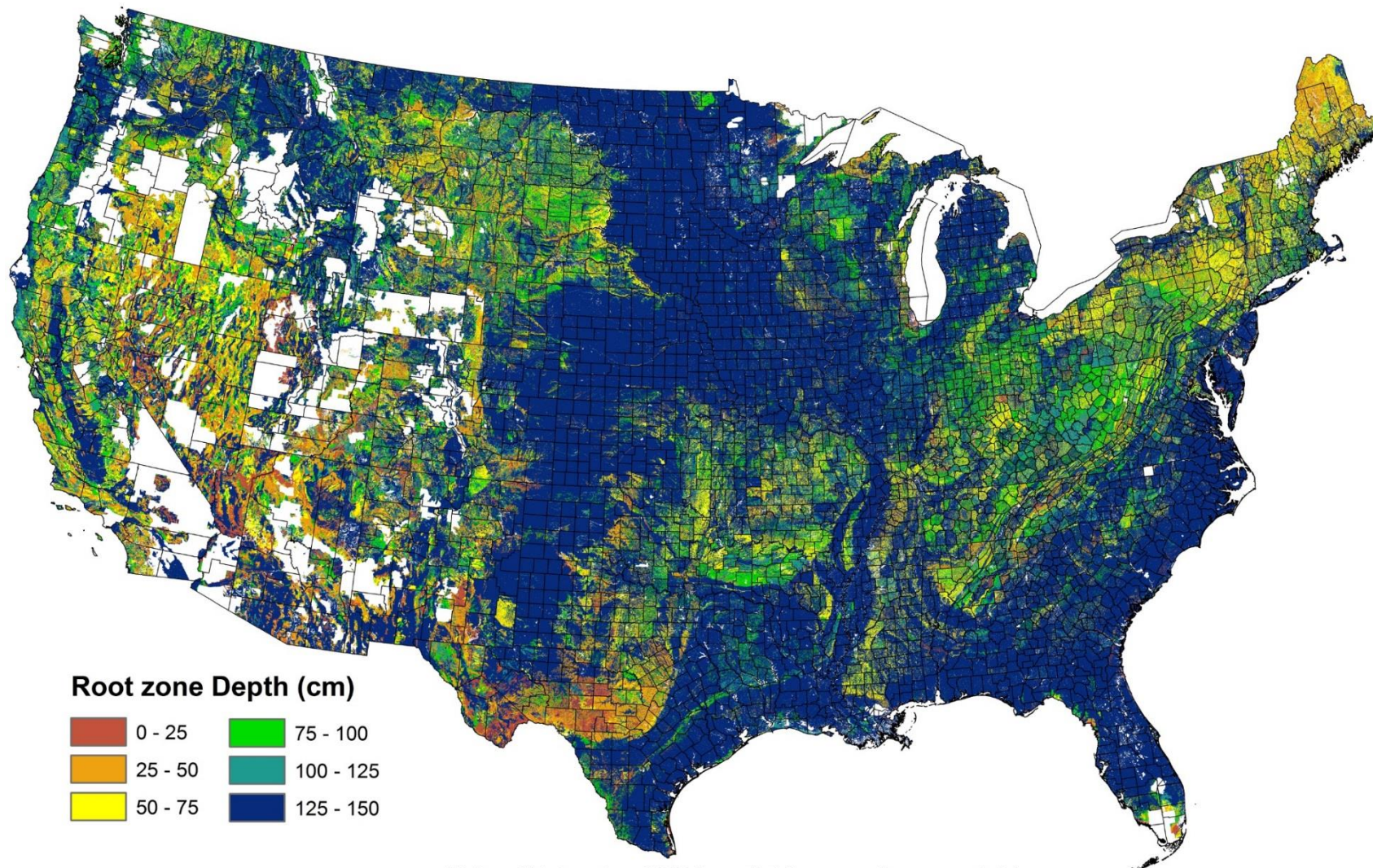
Van Wart et al., 2013. Use of agro-climatic zones to upscale simulated crop yield potential. From: *Field Crops Research* 143, 44-55.



USA Climate Zone Map (Total number = 98)



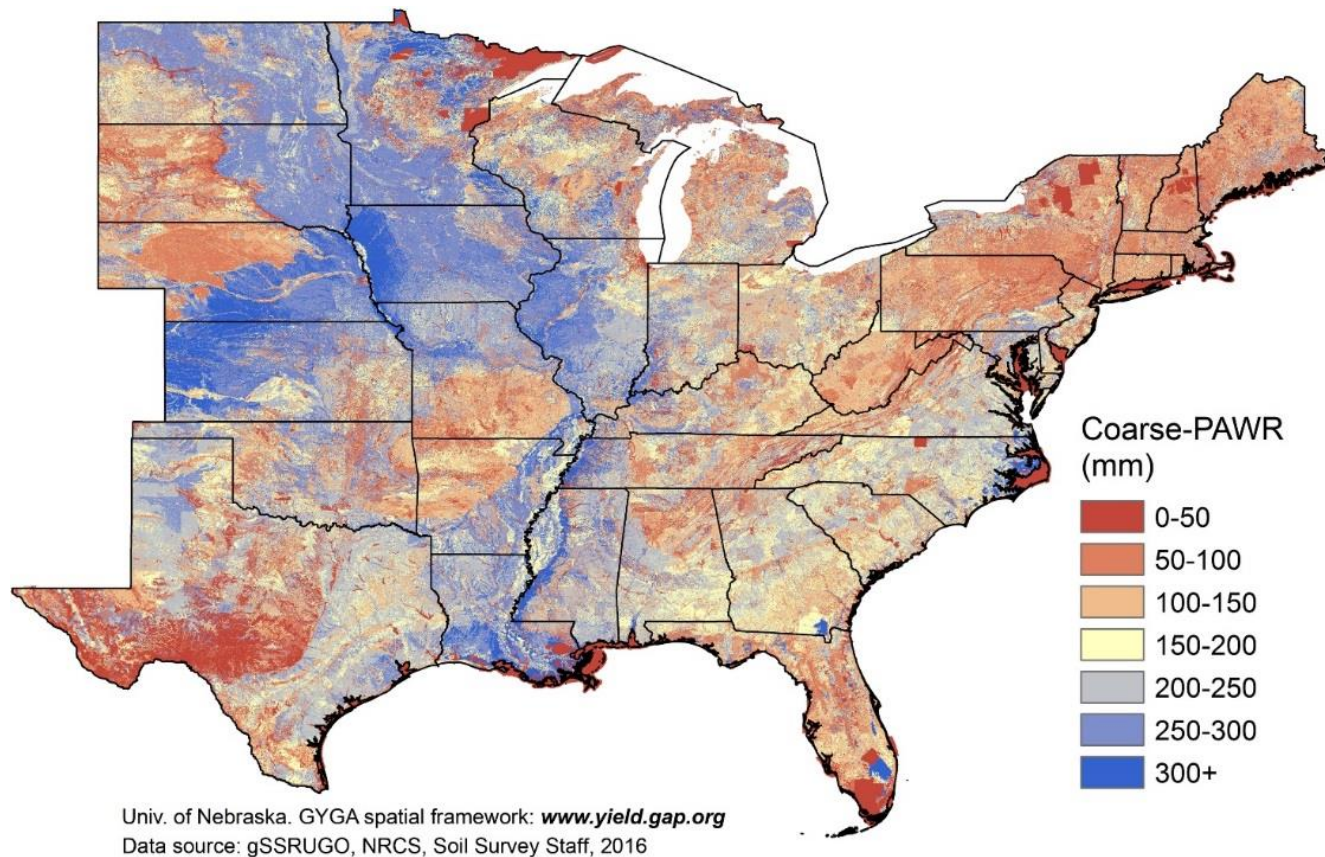
Root zone depth, gSSURGO, NRCS 2016



Univ. of Nebraska. GYGA spatial framework: www.yield.gap.org

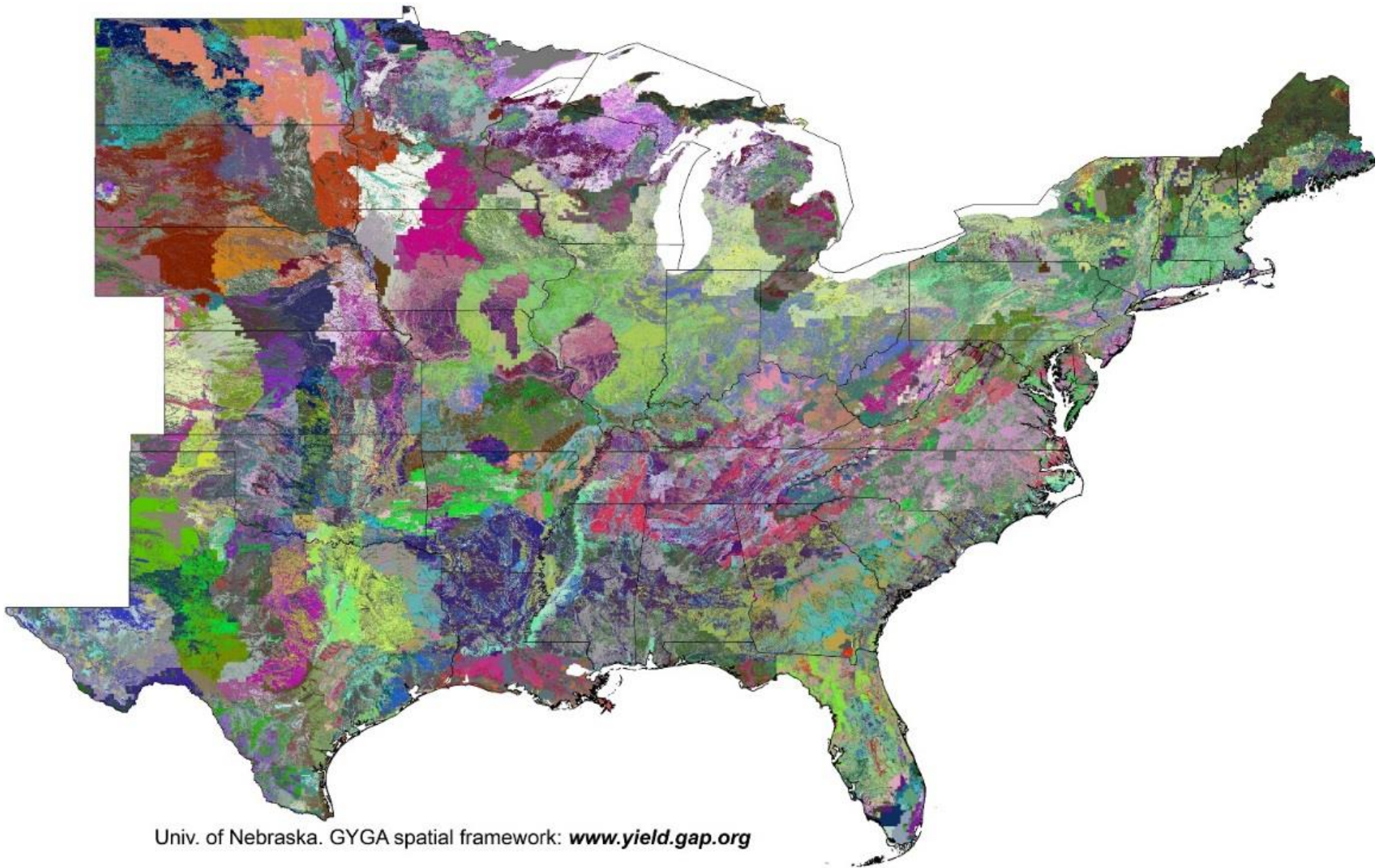
Data source: gSSURGO, NRCS, Soil Survey Staff, 2016

- **Plant available water holding capacity in the rooting zone (PAWR)**
- Spatial resolution of 250 m x 250 m.
- 50 mm PAWR classes



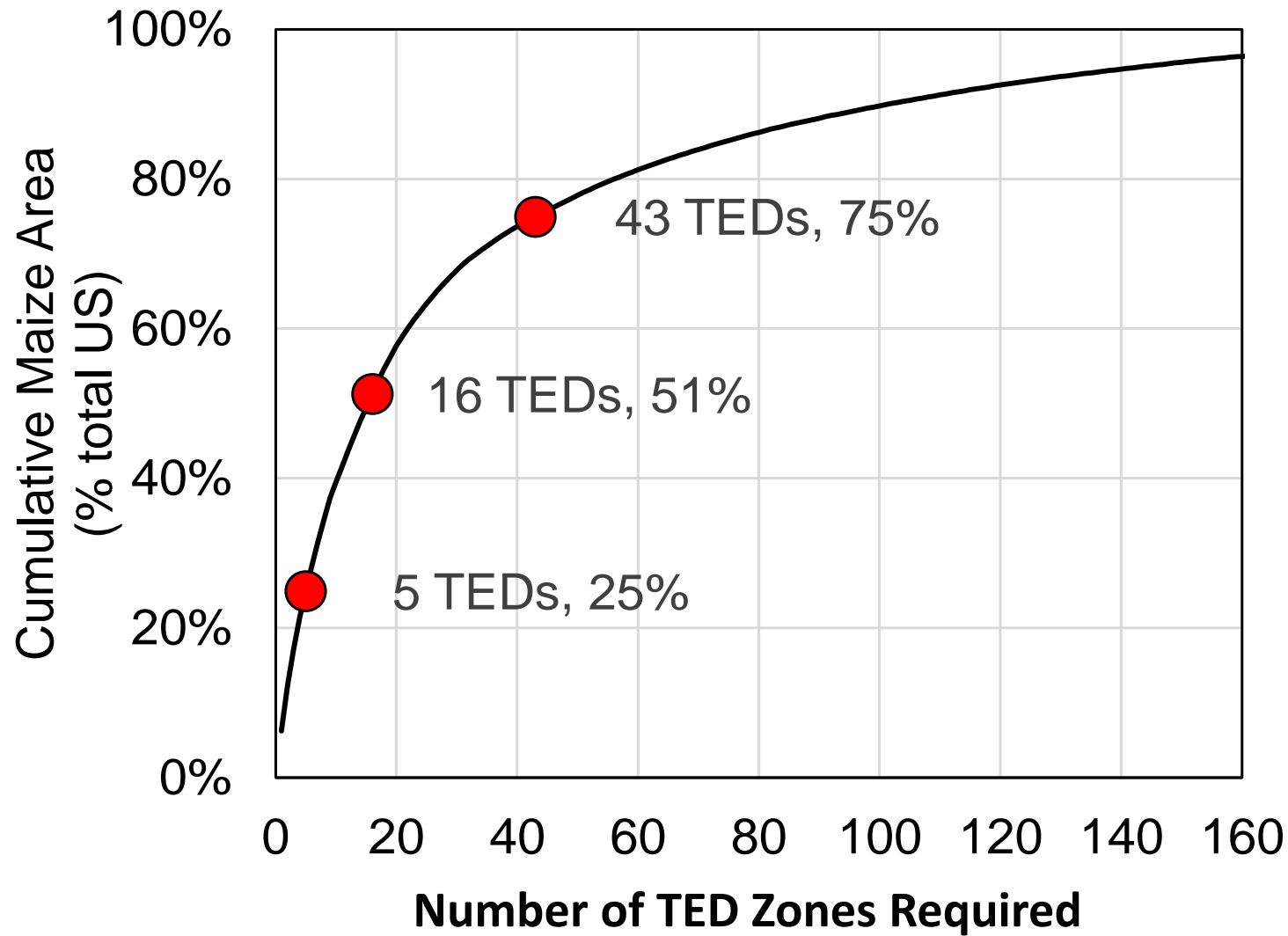
Soil Survey Staff. National Value Added Look Up (valu) Table Database for the Gridded Soil Survey Geographic (gSSURGO) Database for the United States of America and the Territories, Commonwealths, and Island Nations served by the USDA-NRCS. United States Department of Agriculture, Natural Resources Conservation Service. Available online at <https://gdg.sc.egov.usda.gov/>. (2016).

620 TED units, each a unique combination of climate and PAWR

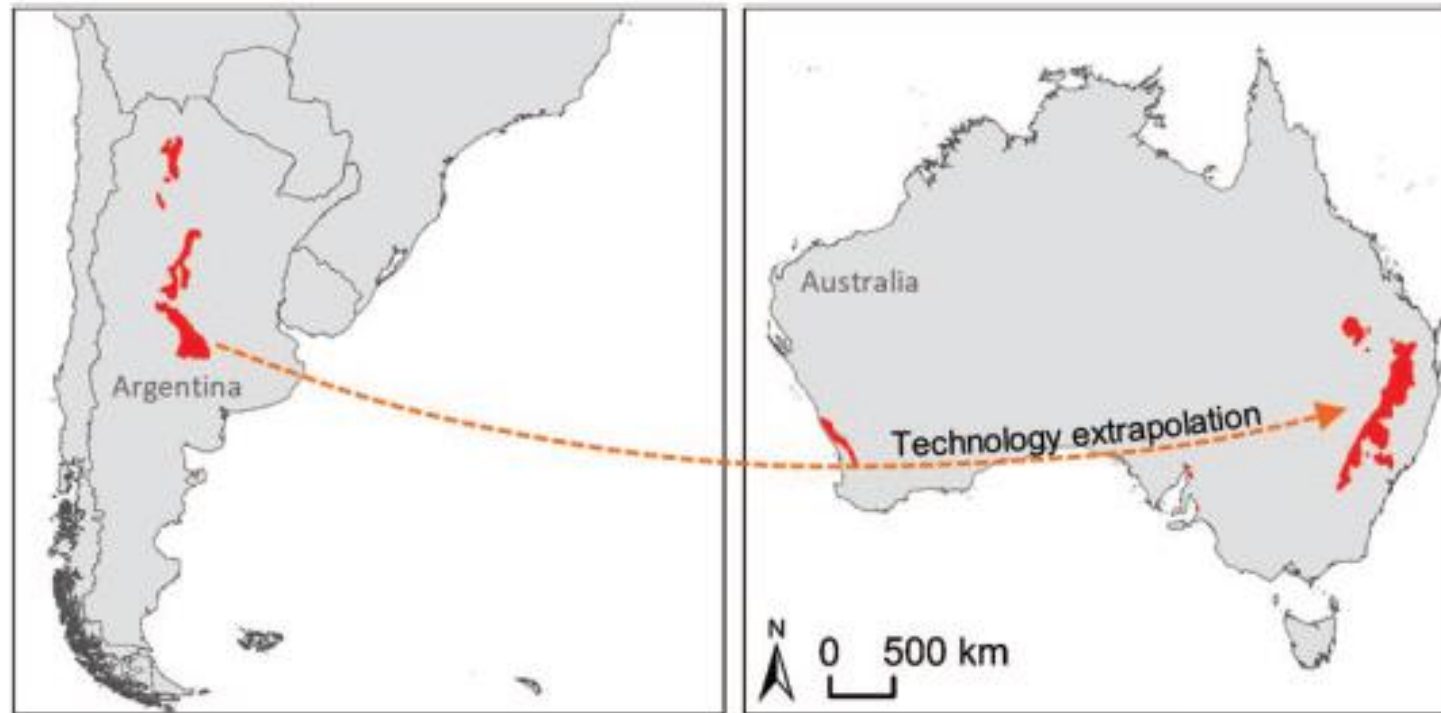


Univ. of Nebraska. GYGA spatial framework: www.yield.gap.org

US maize area is concentrated in relatively few TED zones



Are TEDs an effective spatial framework for technology transfer? Yes....



Australian cropping system	Cropping intensity (crops yr ⁻¹)	Wheat yield (Mg ha ⁻¹)	Mungbean yield (Mg ha ⁻¹)	Net income (USD ha ⁻¹ yr ⁻¹)
Continuous wheat	0.9	4.8 (12%)	-	481 (23%)
Wheat-mungbean	2	4.5 (14%)	1.5 (32%)	841 (37%)
Wheat-mungbean (60 mm threshold)	1.9	4.5 (13%)	1.6 (22%)	841 (34%)

Technology evaluation in the same technology extrapolation domains (TED) on different continents. Argentinean and Australian maps showing a unique climate zone (in red) shared by both countries. Within the climate zone in each country, zones with similar plant-available water holding capacity in the root zone were compared (i.e. the same TED). Table shows the performance of three alternative cropping systems of varying intensity in Gunnedah (Australian location within the TED) in term of simulated water-limited yield potential, yield variation (CV, in brackets), annual net income (expressed as gross income minus variable and overhead costs) and variation in annual income (CV, in brackets).

What would a global farmer-reported database look like?

- Public-sector high quality, high spatial resolution database
- Long-term (20+ years) and current weather data
- Soil properties governing crop growth and environmental performance
- Water resources (stream flows, groundwater & reservoir stores)
- **Farmer-reported, geo-referenced farmer-owned and controlled database** on field management (also required to support robust crop insurance programs and environmental monitoring)
- Crop rotation, tillage method, cover crops, yield, crop cultivar and maturity rating, sowing date, plant population and planting pattern, N rate/form/timing of application, P and K rates, micronutrient use, pesticide use, water regime (fully irrigated, partial irrigation, rainfed; if irrigated, amount applied)
- Private sector adds value through development of products: decision-support tools, forecasts, crop varieties, etc.

Holy Grail

- ❑ Stable human population, followed by a gradual and orderly decline
- ❑ Sustainable food security for 10-11 billion
 - It will require **Global Big Data** Cooperative under farmer governance, and IT solutions to use them
 - Robust geospatial framework that supports rapid tech transfer and acceleration in yield growth rates on existing farm land, especially in breadbaskets
- ❑ The good news: It's possible to achieve!

THANK YOU!