RNRF Congress: Food Production Adaptation to Climate Change,
9-10 October 2014, Washington DC

Adapting food production to climate change: Agronomic responses and tools

Kenneth G. Cassman
University of Nebraska

University of Nebraska Lincoln

Global Yield Gap Atlas

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Specifics: Dealing With Harsh and Uncertain Climate

- **Local adaptation (*lots of options to deal with CC*)**
  - Importance of soil quality
  - Tactical field-level crop management options
  - Strategic options: Investment in irrigation, new crops, crop rotations and farming systems
- **A few essential tools (*some not receiving adequate attention*)**
  - Public access to weather data: good quality, long-term, daily time step
  - Continuous genetic improvement in crop stress tolerance

Fundamental relationship in rainfed systems: Strong negative correlation between yield and risk

- In favorable rainfed systems with generally adequate and reliable rainfall and good quality soils, yields are high and risk is low
- In harsh rainfed areas with less rainfall and/or shallow soils with low water holding capacity, yields are low and risk is high
- If climate change makes rainfed crop areas "harsher", adaptation must focus on increasing plant-available water supply and reducing risk

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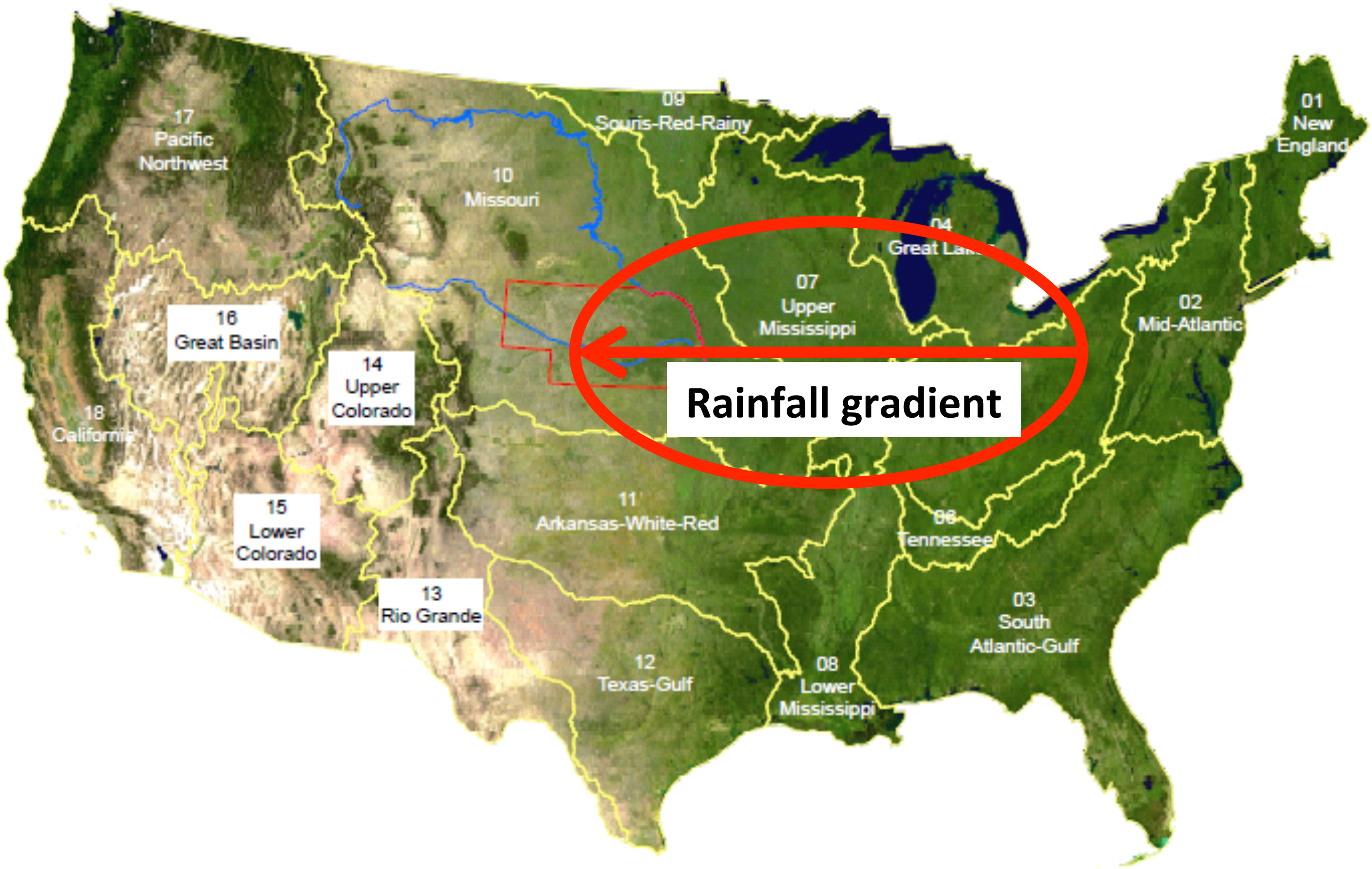
US Corn Belt: 11% of national land area and the largest and most productive agro-ecosystem in the world



Rainfall gradient

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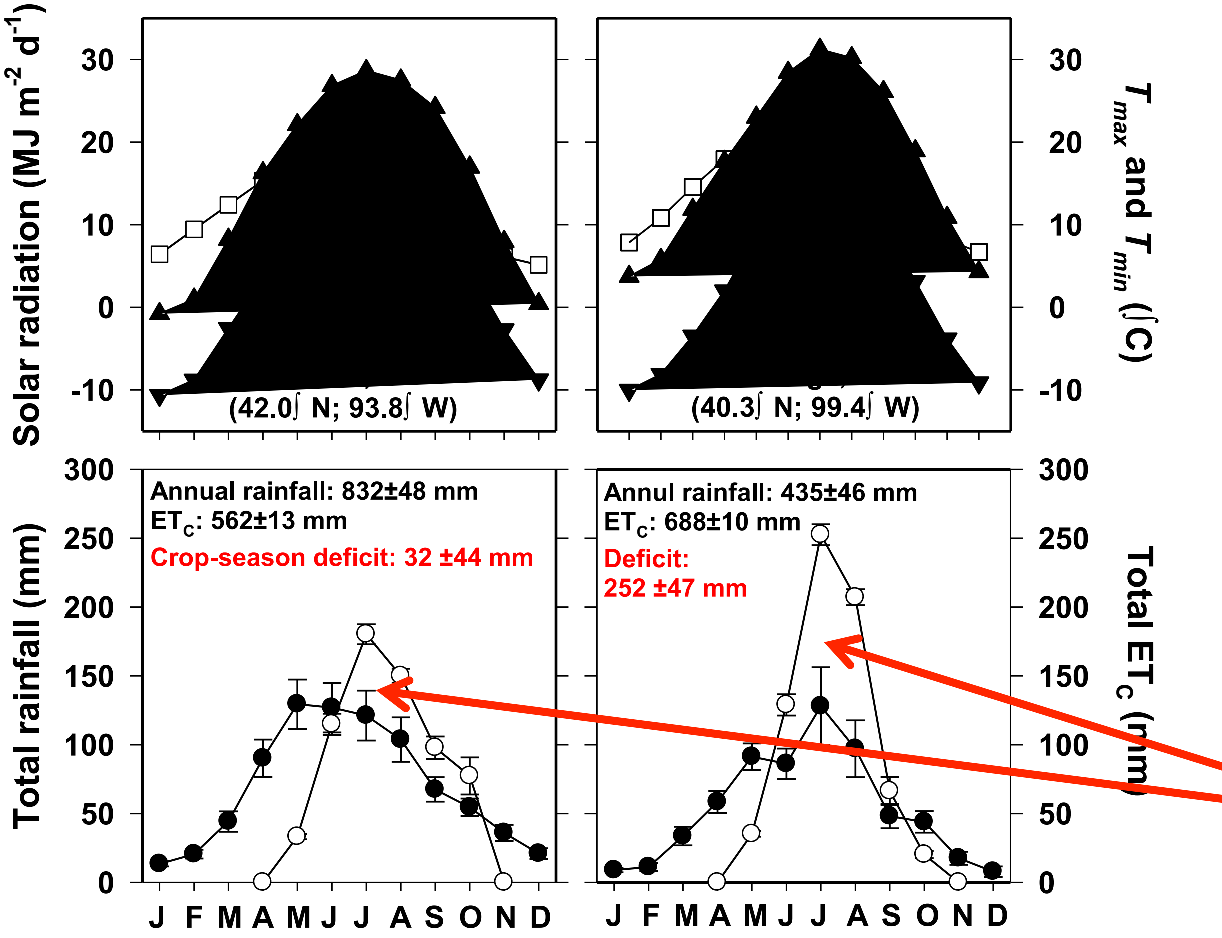
Rainfall, temperature, soil depth and texture determine plant-available water supply for crops and length of growing season

Solar radiation (□), T max (▲), T min (▼), rainfall (●), crop ET (○)



30-yr averages

Highly favorable rainfed crop agro-ecosystem in the central US Corn Belt (Ames IA, left),

versus….

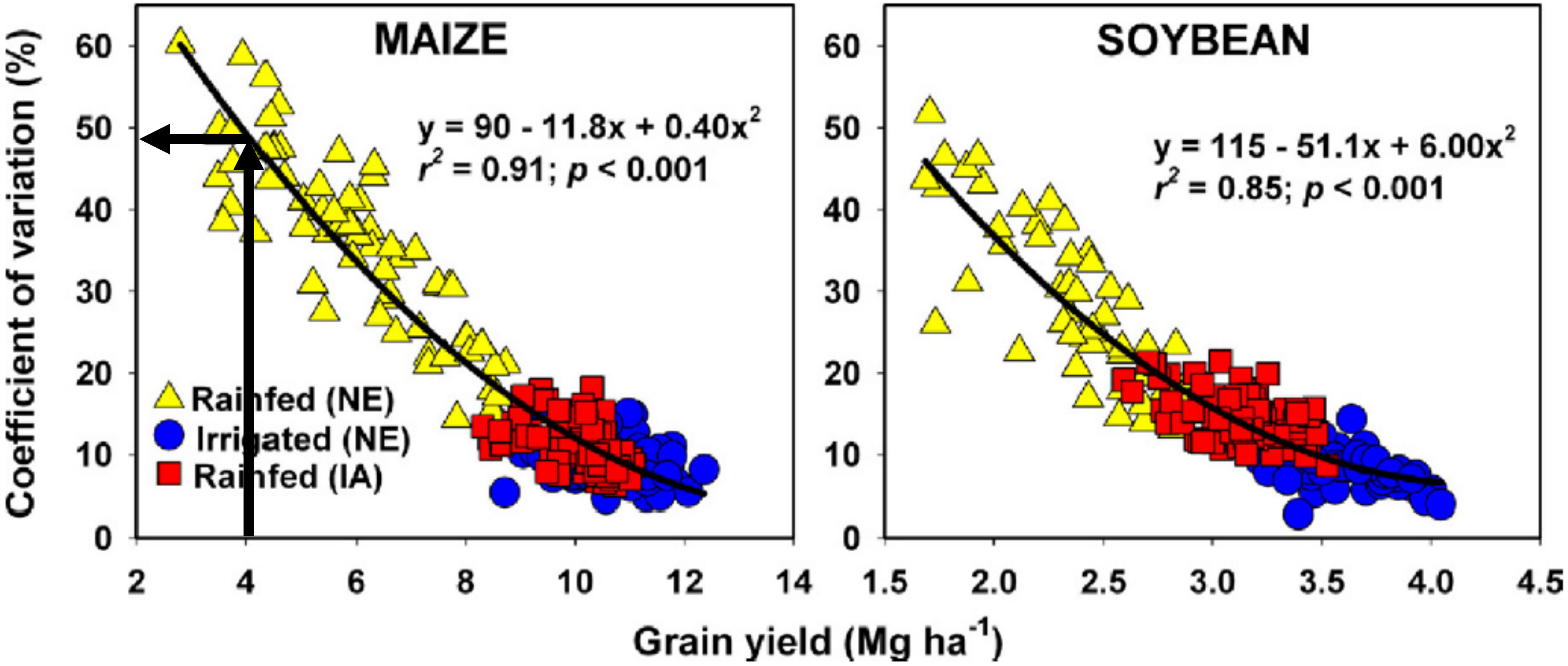
Harsh and uncertain rainfed environment in the western US Corn Belt (Holdrege NE, at right)

Magnitude of water deficit is 8-fold greater in Holdrege compared to Ames.

Source: *Crop Ecology*, 2011

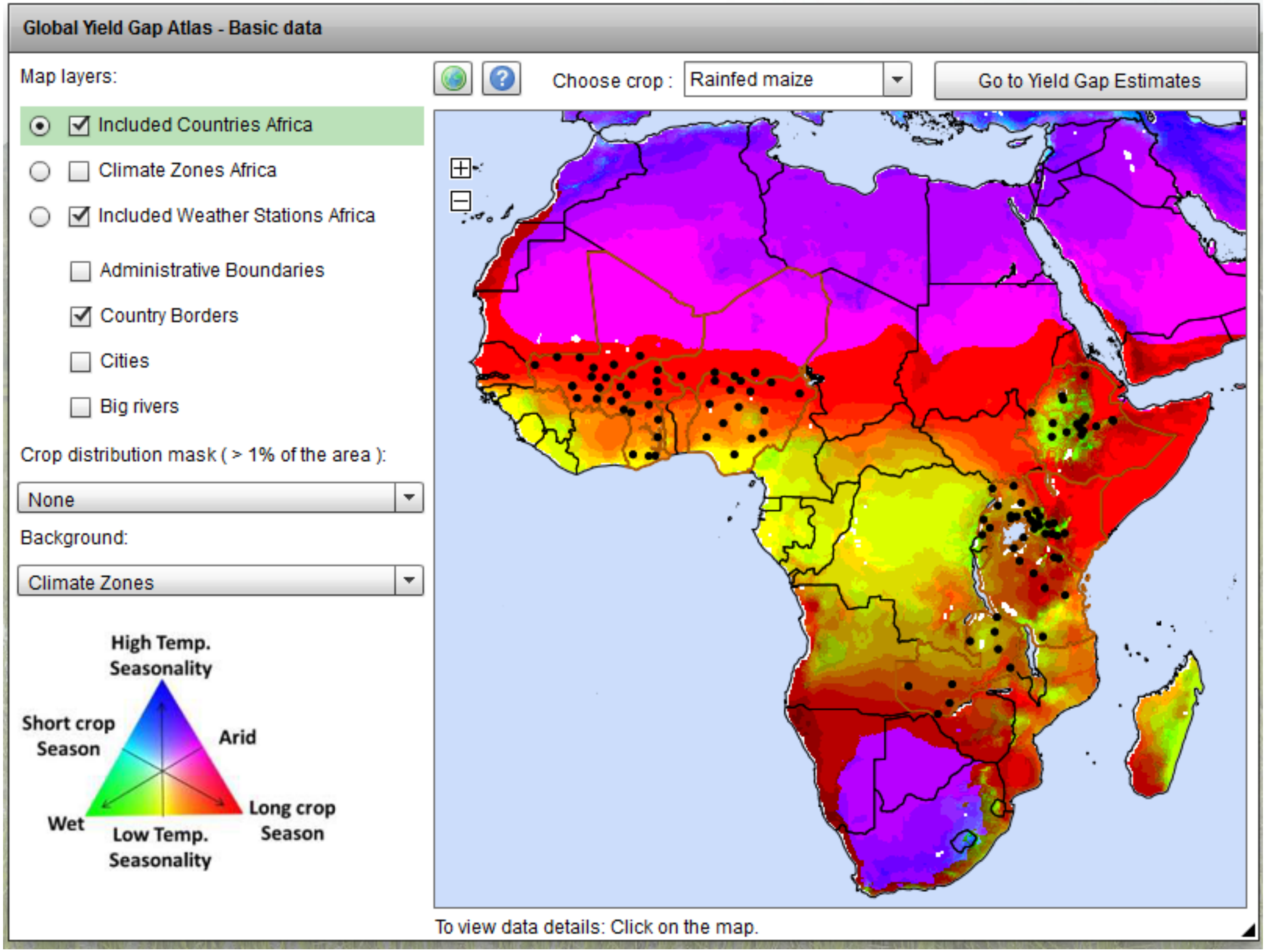
In the US Corn Belt, rainfed yield variability decreases in regions with higher average yield

County data from Iowa (reliable rainfall) and Nebraska (less and variable rainfall, irrigation)



Source: Grassini et al., 2014. In *Crop Physiology,* Oxford Academic Press, pp 15-42.

Climate zonation (from www.yieldgap.org)



Global Yield Gap Atlas - Basic data

Map layers:

● ☑ Included Countries Africa
○ ☐ Climate Zones Africa
○ ☑ Included Weather Stations Africa
☐ Administrative Boundaries
☑ Country Borders
☐ Cities
☐ Big rivers

Crop distribution mask (> 1% of the area): None

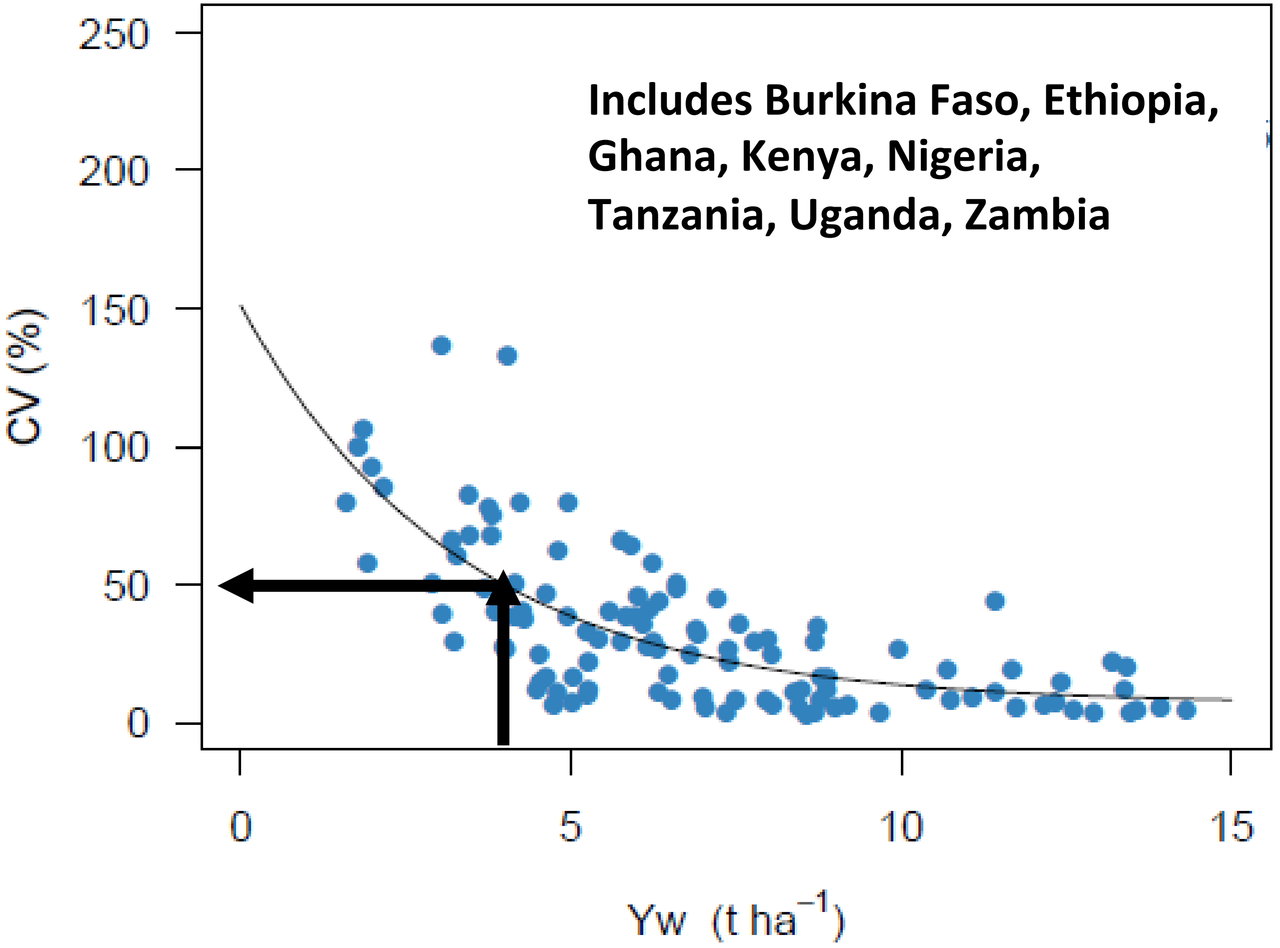
Background: Climate Zones

Choose crop : Rainfed maize

To view data details: Click on the map.

Van Wart et al., 2013. Field Crops Research 143, 44-55.

Temporal variation in rainfed maize yield potential (Yw) in relation to simulated Yw with long-term weather data in 10 Sub-Saharan Countries



Includes Burkina Faso, Ethiopia, Ghana, Kenya, Nigeria, Tanzania, Uganda, Zambia

Source:
Global Yield Gap Atlas (www.yieldgap.org)

Figure provided by Nicolas Guilpart

100 cm effective root zone

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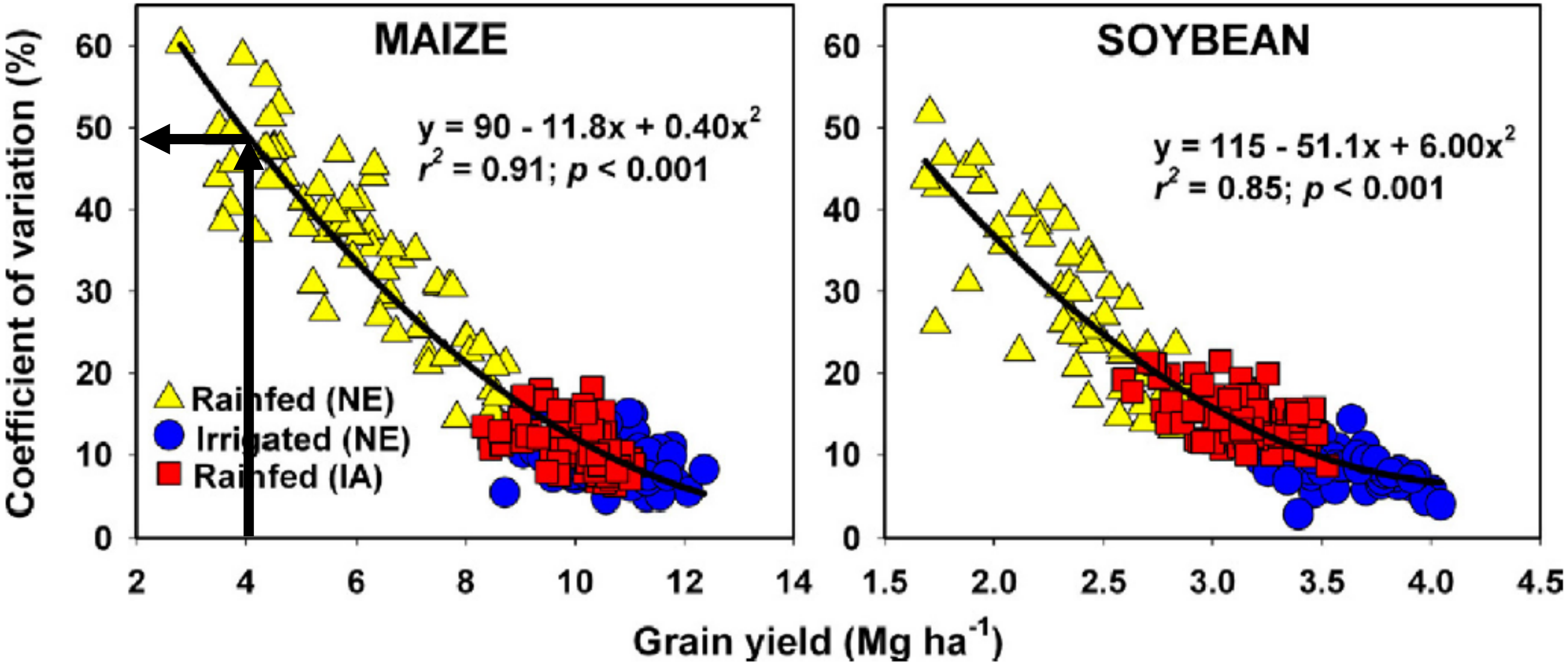

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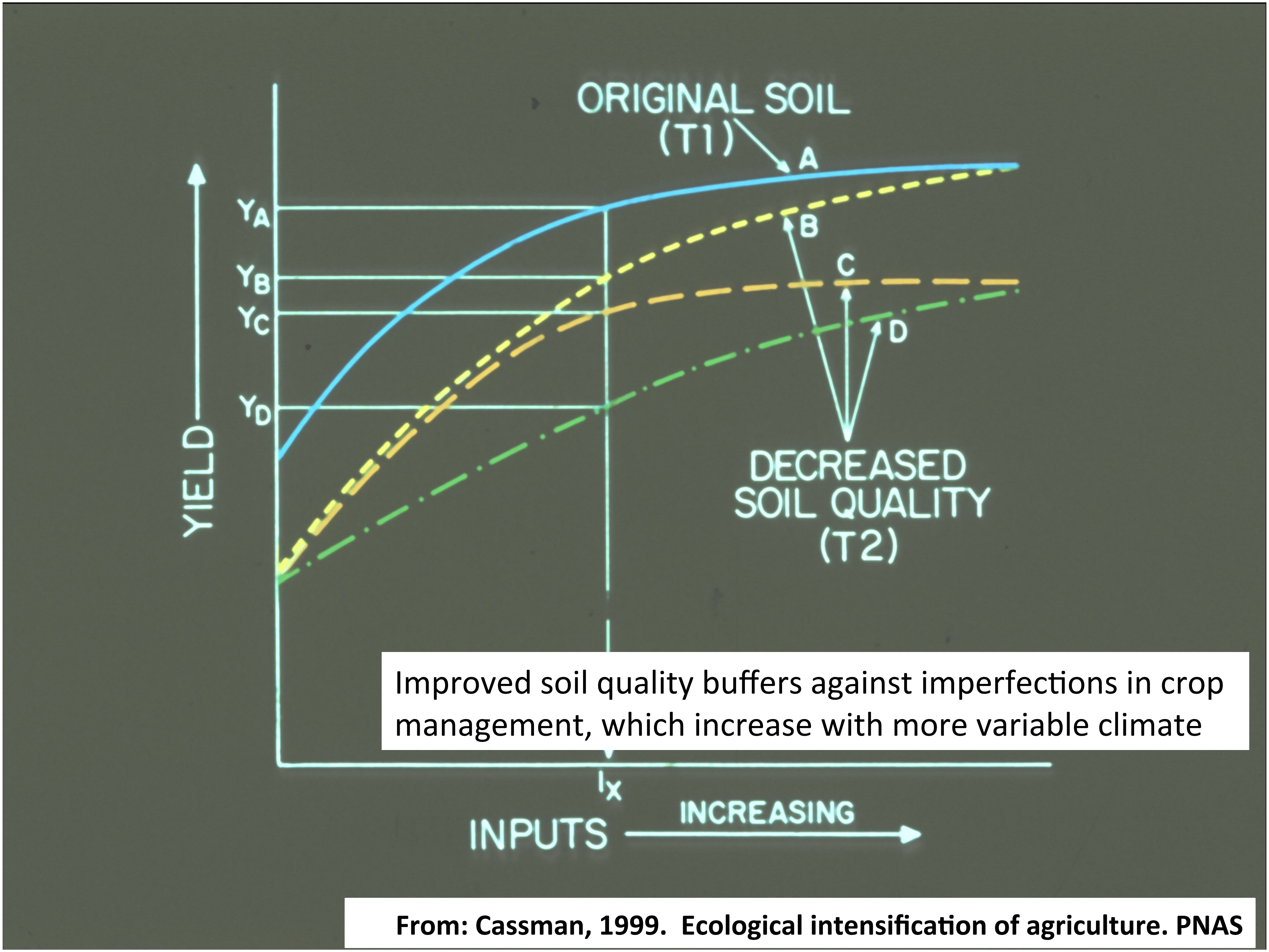
3 Hypotheses: soil quality and climate chage

1. **Improved soil quality mitigates negative impact of climate change on crop yields and risk**



Improved soil quality buffers against imperfections in crop management, which increase with more variable climate

From: Cassman, 1999. Ecological intensification of agriculture. PNAS

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Tactical field-level crop management options

- **Options with low barriers to adoption can occur quickly**
  - Adjusting plant density, planting date, crop maturity
- **Options with larger barriers have longer time-frame**
  - Changes in tillage (no-till, reduced tillage) and construction of soil and water conservation structures
- **Options requiring substantial new expertise and investment in research and development**
  - New crops
  - Alternative cropping systems
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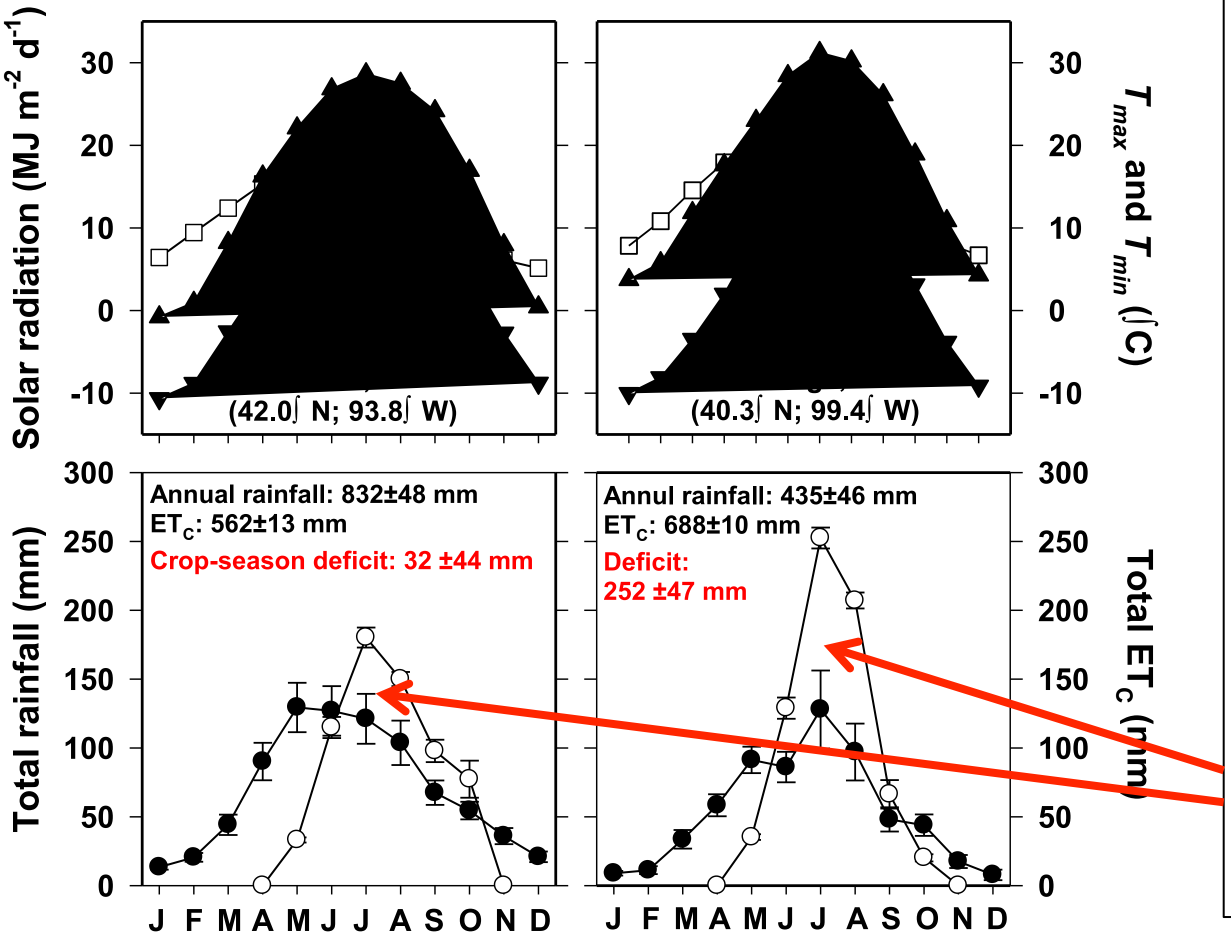

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Source: *Crop Ecology*, 2011

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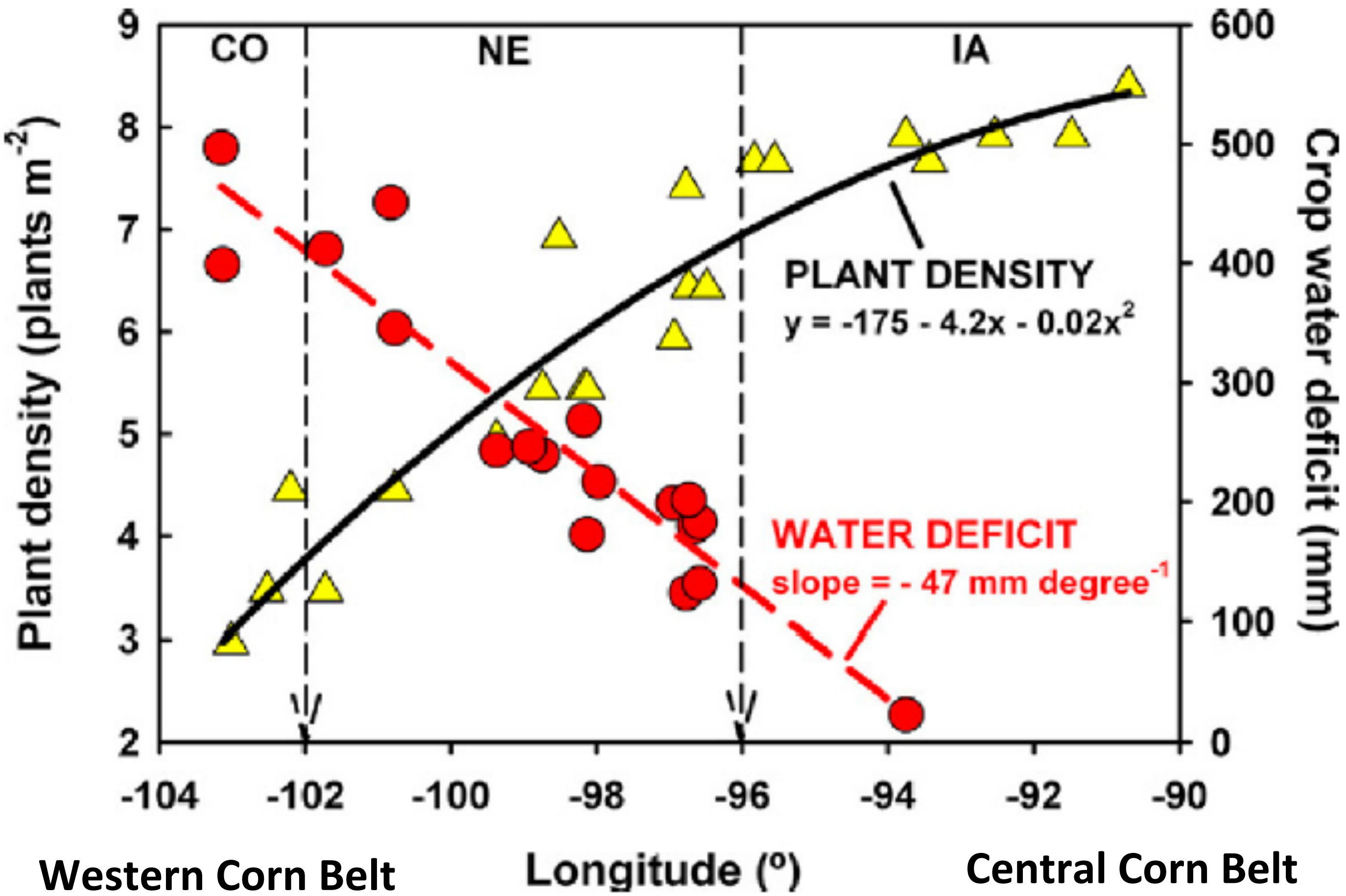
How farmers respond to climate and technologies



Across the USA Corn Belt, farmers use lower plant density (controlled by the seeding rate) in regions with greater water deficits (rainfall versus evapo-transpiration (ET) during the growing season.

Source: Grassini et al., 2011, Field Crops Research

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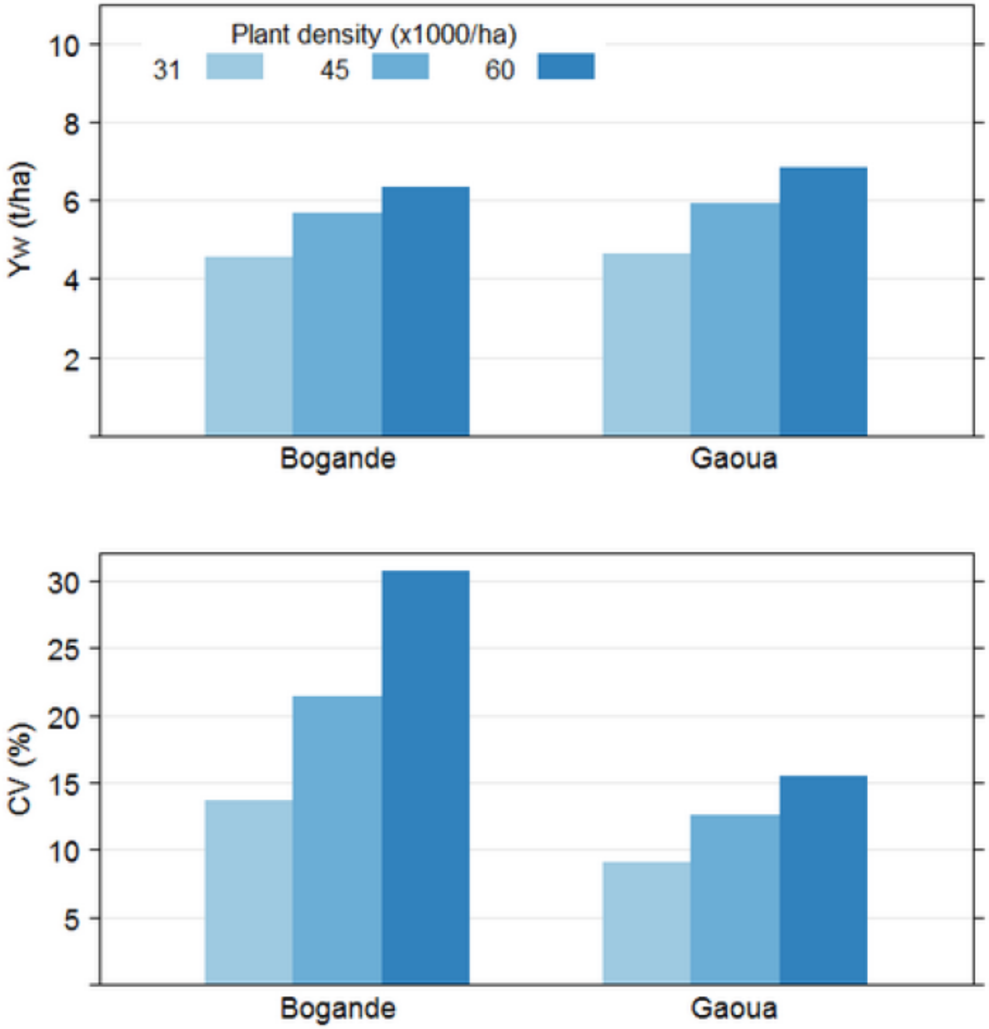
Impact of plant density on simulated rainfed maize yield potential in Burkina Faso (harsh rainfed environment)



<u>Rainfall:</u>

Bogande = 450 mm/year

Gaoue = 560 mm/yr

<u>Average Yield (all plant densities):</u>

Bogande = 5.4 t/ha

Gaoue = 5.8 t/ha

<u>Range in Coefficient of Variation (CV%):</u>

Bogande = 14 to 31%

Gaoue = 9 to 15%

Source: Global Yield Gap Atlas, provided by Dr. Nicolas Guilpart

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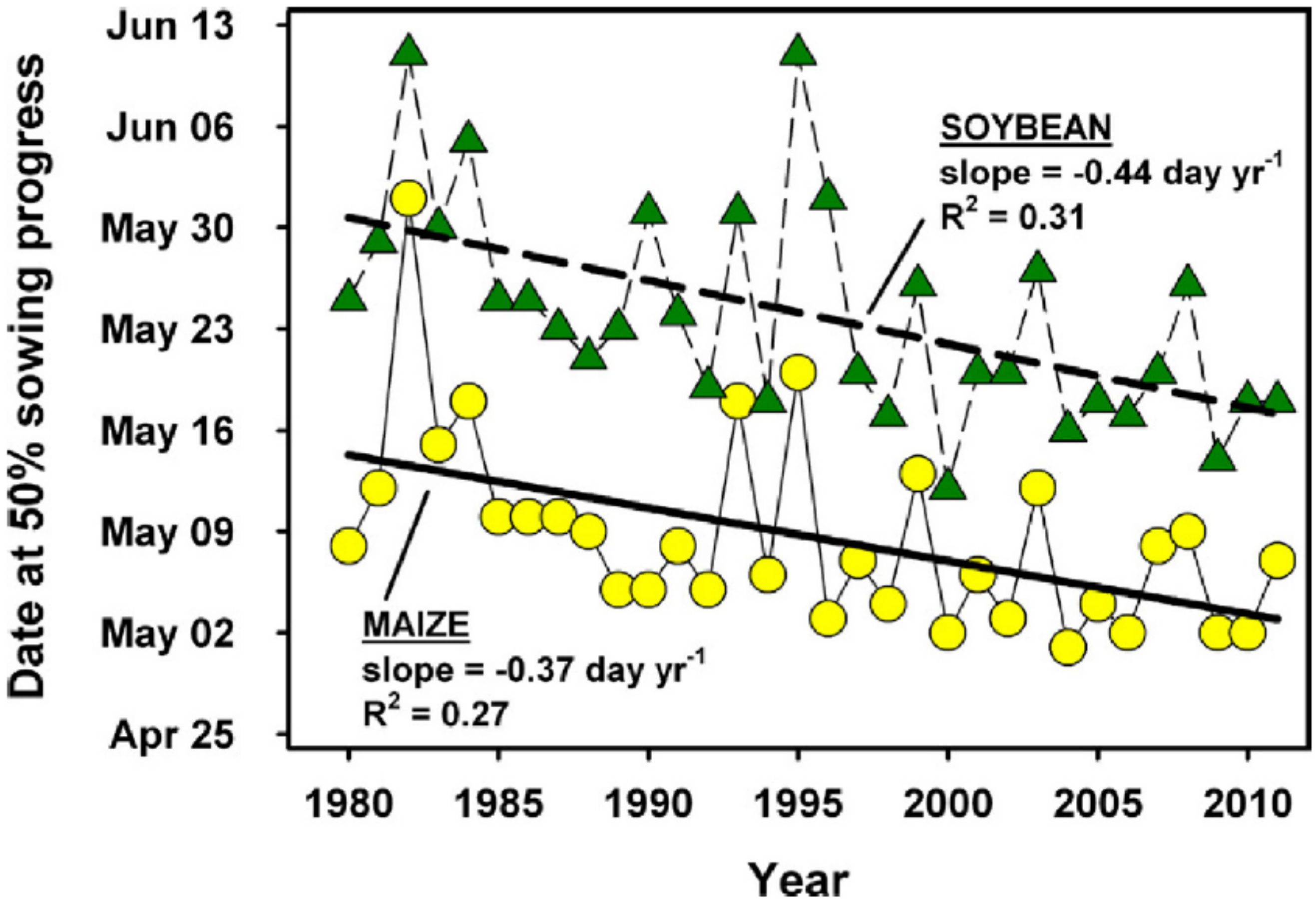
Farmers can respond rapidly to changing change if improved technologies are available



Nebraska farmers have steadily planted maize and soybean crops earlier in spring in response to improved planting equipment, seed treatments that protect against disease and insects, and slight warming spring temperatures

Source: Grassini et al., 2014. In *Crop Physiology,* Oxford Academic Press, pp 15-42

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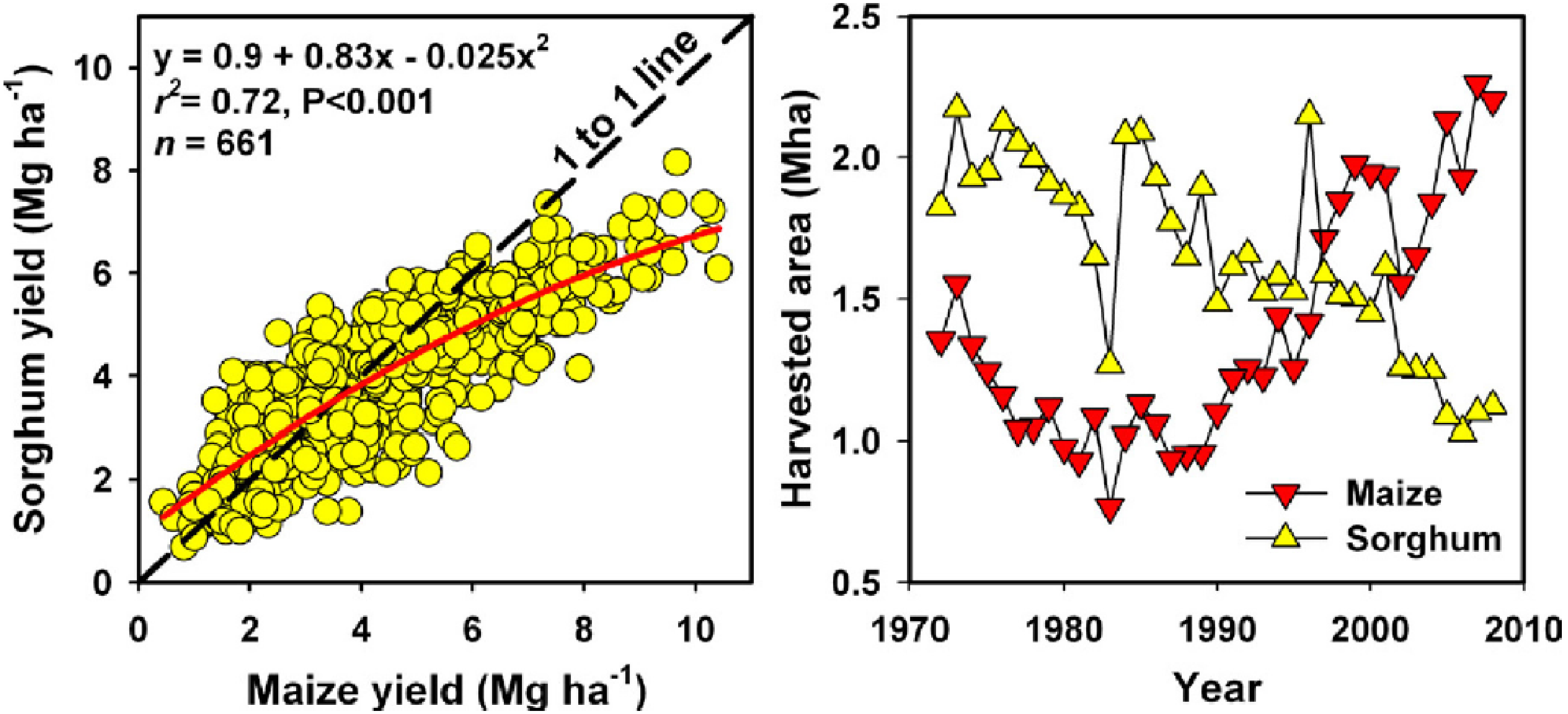
Crop selection in water-limited environments: the case of sorghum versus maize in NE and KS, USA



Source: Grassini et al., 2014. In *Crop Physiology,* Oxford Academic Press, pp 15-42

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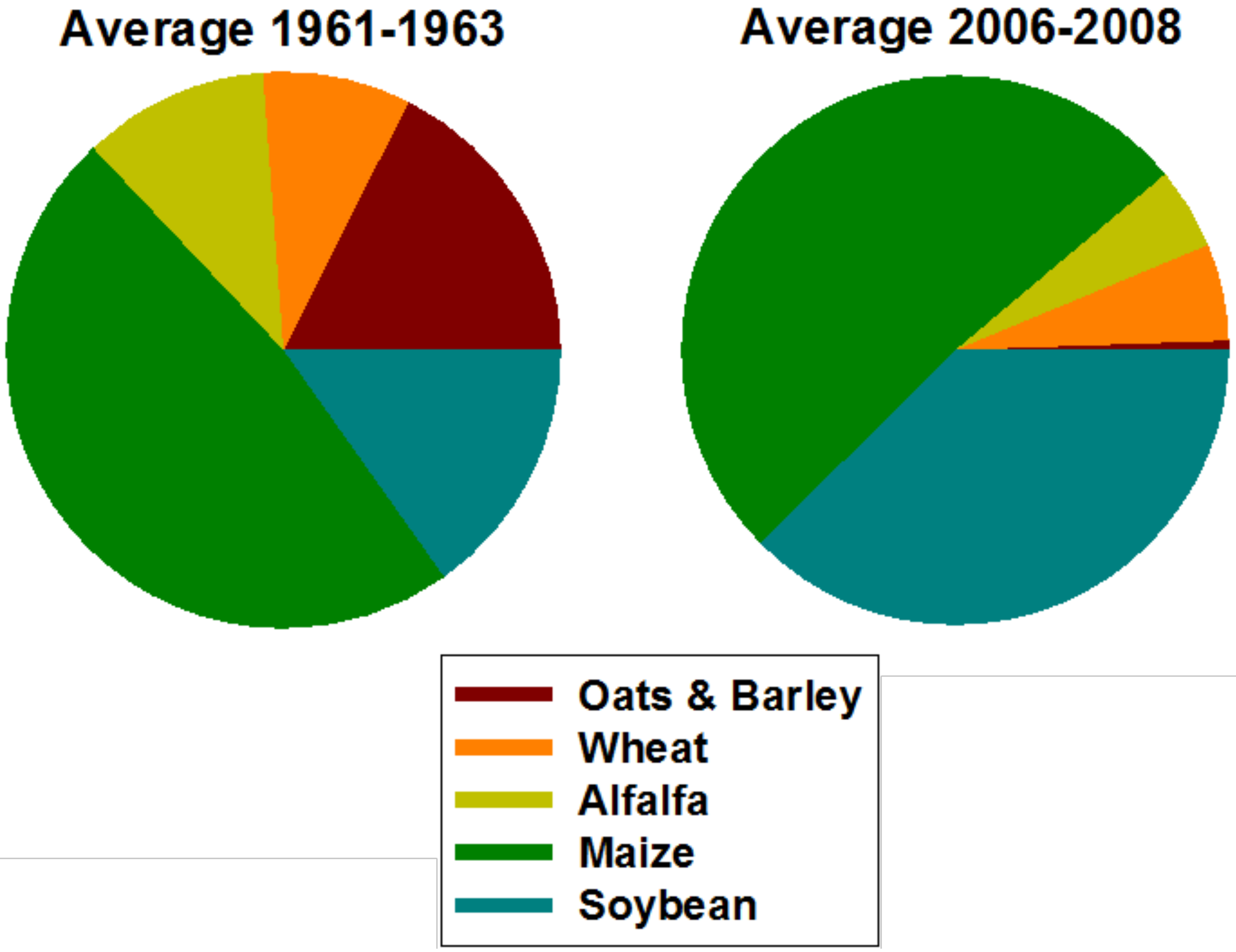
Simplification of cropping systems in the U.S. Corn Belt

From: Connor, Loomis, Cassman. 2011. *Crop Ecology*, Cambridge Univ. Press



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How much diversity is enough to ensure sustainable staple crop production systems with changing climate?

- **Depends heavily on favorability of climate because more favorable climates have greater options with regard to crop species and cropping intensity**
  - **Warm humid tropical, good soils (deep and well structured soils (Cerrado)>>**
  - **Warm temperate regions with long growing season, good soil and rainfall (Balkans, Pampas, parts of southern China)>>**
  - **Cool temperate regions with short growing season, good soil and rainfall (Ukraine, Russia, northern Europe, most of USA Corn Belt)>>**
  - **Warm temperate or tropical regions with low rainfall and/or poor soils (Australia, Mediterranean zones; semi-arid tropics)**
  - **Where do perennial grains fit in?**

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- **Options requiring substantial new expertise and investment in research and development**
  - New crops
  - Alternative cropping systems
  - **Investment in irrigation equipment, infrastructure, policies**

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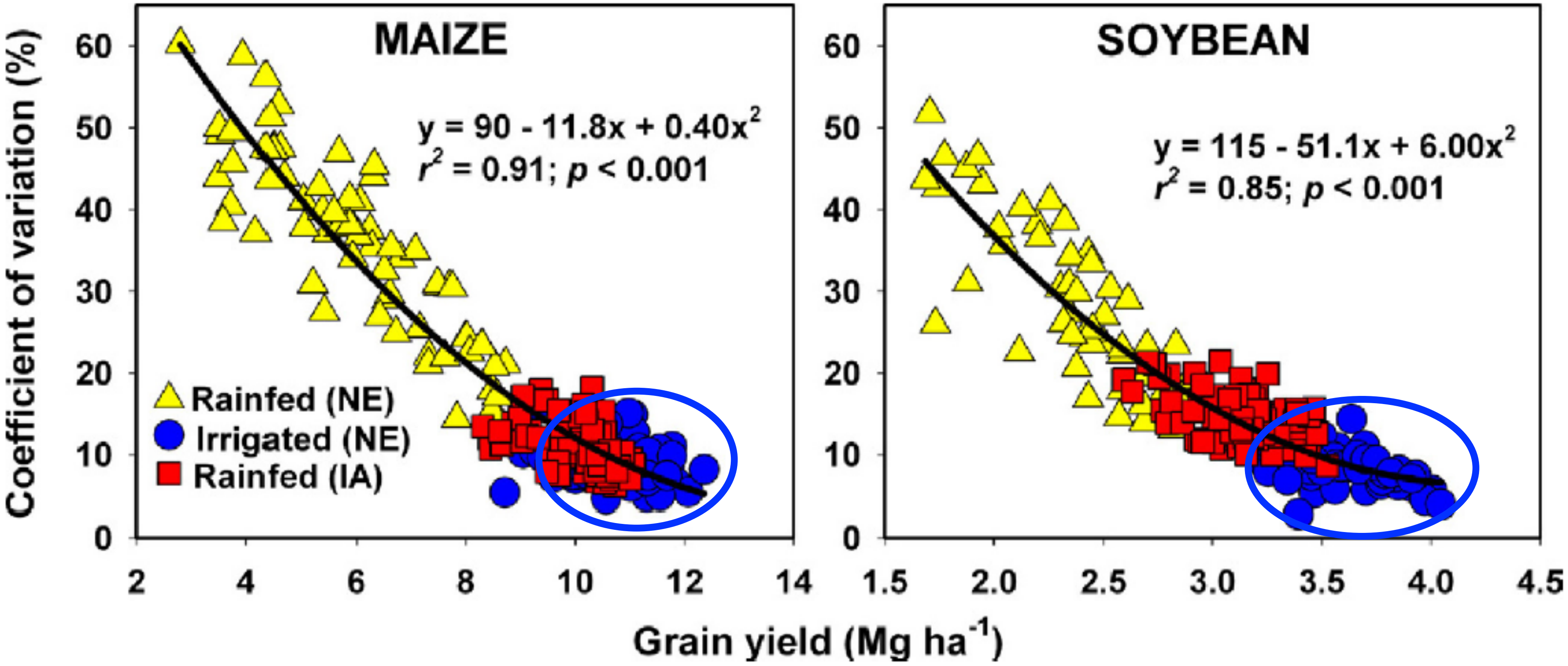
Irrigated agriculture developed along the Nile River in Egypt and in parts of the Fertile Crescent 6,000-8,000 years ago

Photos: K.G. Cassman

Fundamental Relationships:
Yield variability decreases in systems with higher yield

County-level data from Iowa (good rainfall) and Nebraska (less rainfall, irrigation)



Source: Grassini et al., 2014. In *Crop Physiology,* Oxford Academic Press, pp 15-42.

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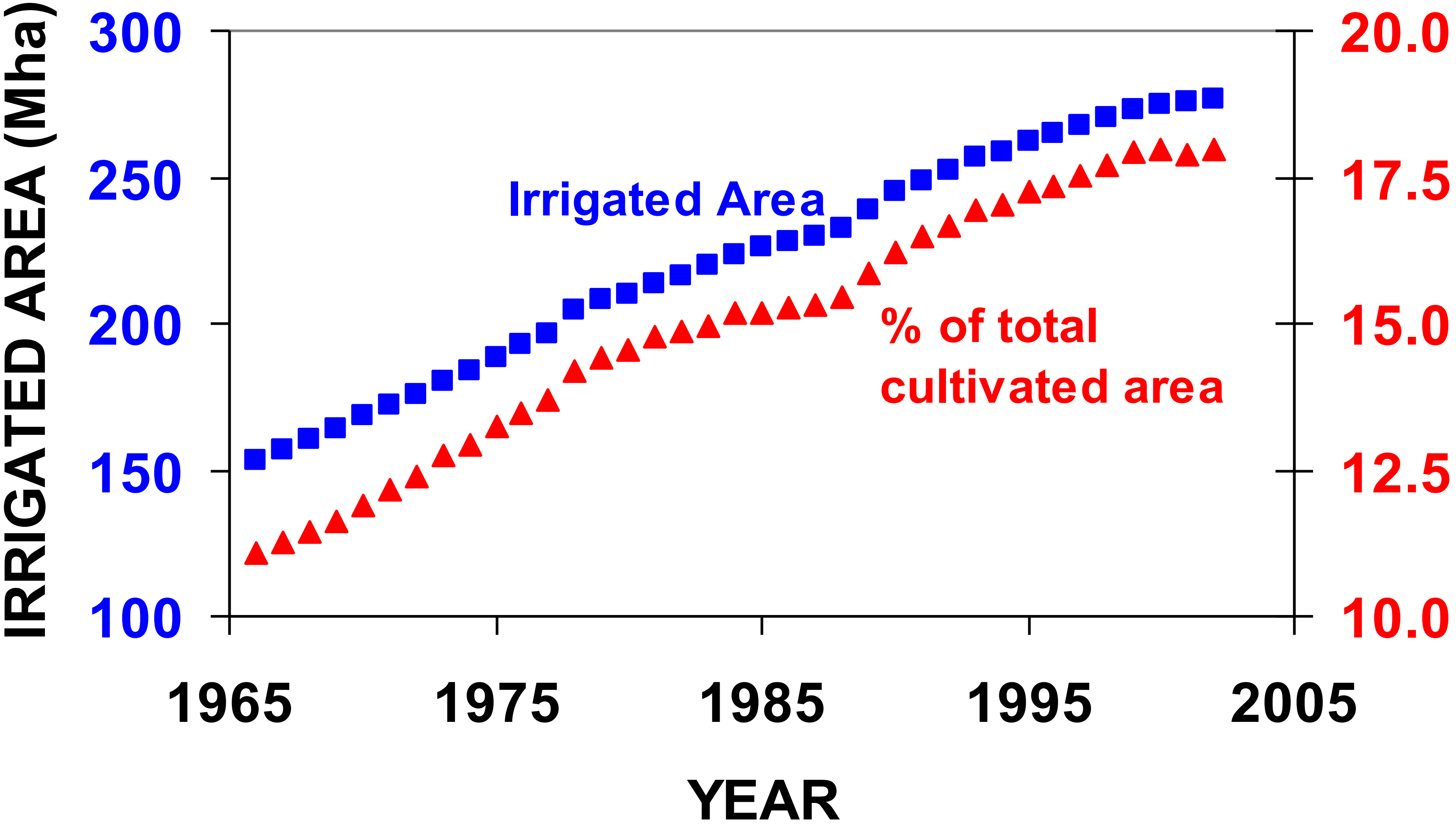
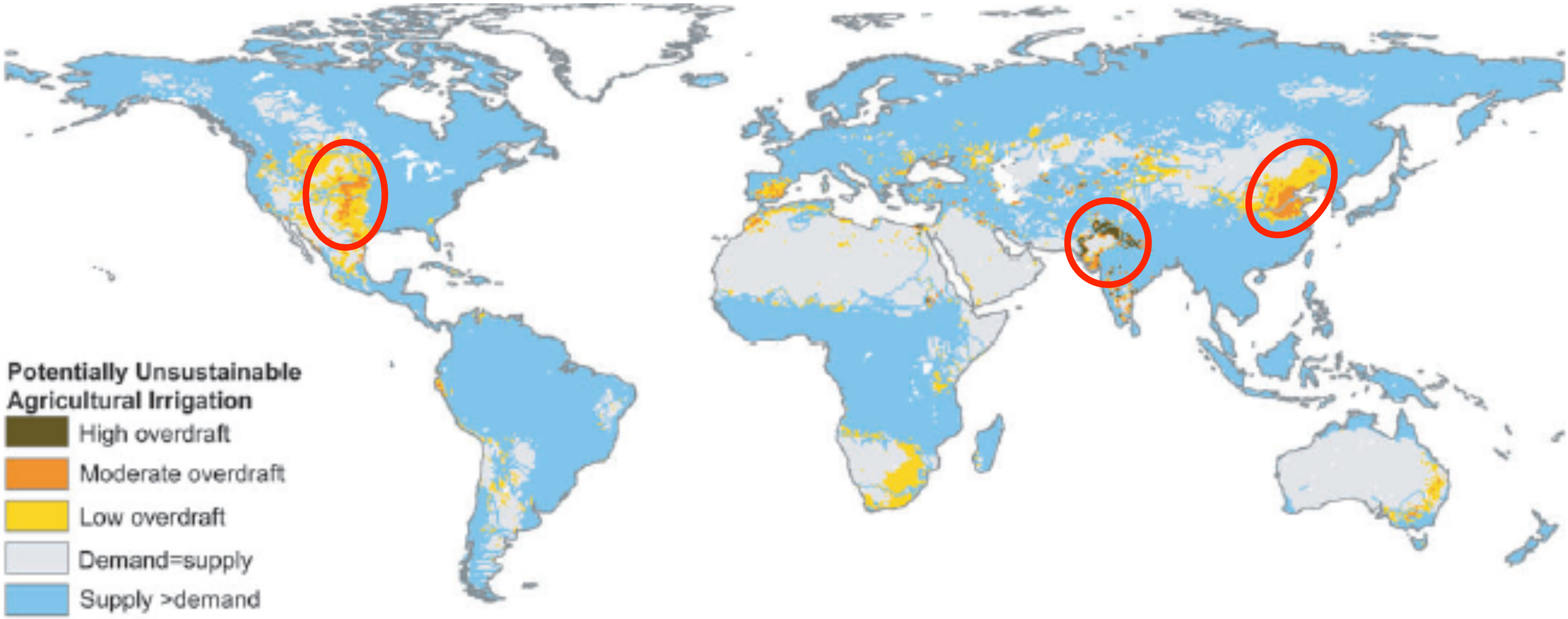
Global irrigated crop production area, 1966-2004

[currently represents ~18% of total crop area yet accounts for ~40 of total food production]



Regions where irrigated agriculture is threatened by over-drafting, salinization, or both



The "big three" aquifers for global food security:

North China Plain, Indo-Gangetic Plain, U.S. Great Plains

Ensuring long-term viability of irrigated agriculture is a key component of climate-smart agriculture

- Integrity of reservoirs, and conveyance structures
- Informed, effective, and efficient policies, regulations, and institutions to avoid over-drafting and avoid negative environmental impact
- Public and private sector investment in research, development and human resources to improve efficiency and advance irrigation technologies and equipment for both large-scale and small-scale farms and farming systems

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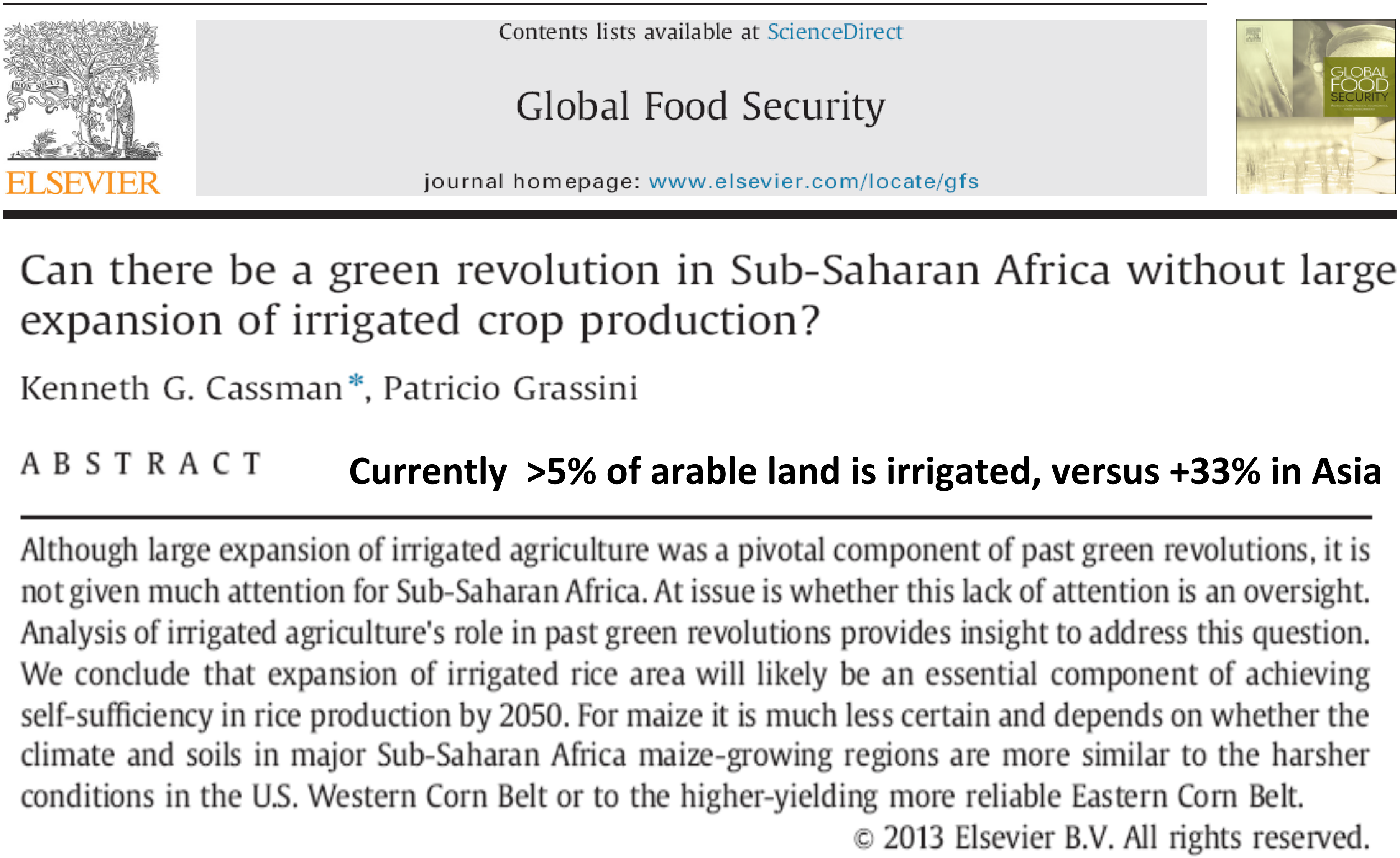
Global Food Security 2 (2013): 203-209



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

Can there be a green revolution in Sub-Saharan Africa without large expansion of irrigated crop production?

Kenneth G. Cassman*, Patricio Grassini

ABSTRACT

Currently >5% of arable land is irrigated, versus +33% in Asia

Although large expansion of irrigated agriculture was a pivotal component of past green revolutions, it is not given much attention for Sub-Saharan Africa. At issue is whether this lack of attention is an oversight. Analysis of irrigated agriculture's role in past green revolutions provides insight to address this question. We conclude that expansion of irrigated rice area will likely be an essential component of achieving self-sufficiency in rice production by 2050. For maize it is much less certain and depends on whether the climate and soils in major Sub-Saharan Africa maize-growing regions are more similar to the harsher conditions in the U.S. Western Corn Belt or to the higher-yielding more reliable Eastern Corn Belt.

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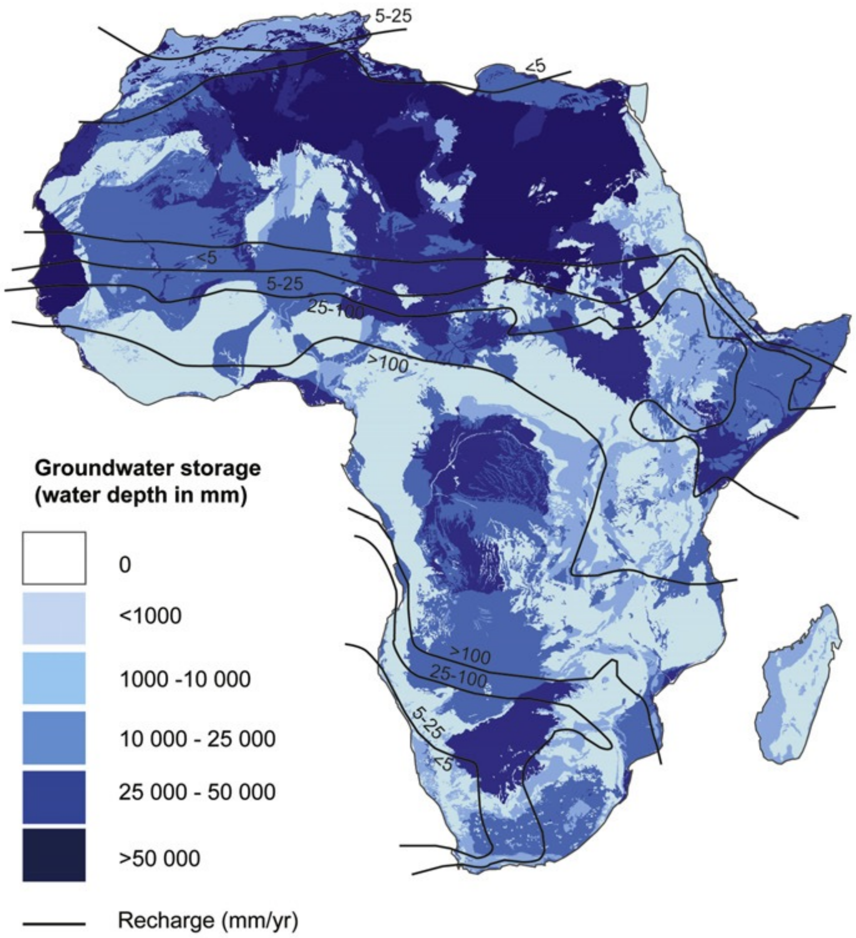
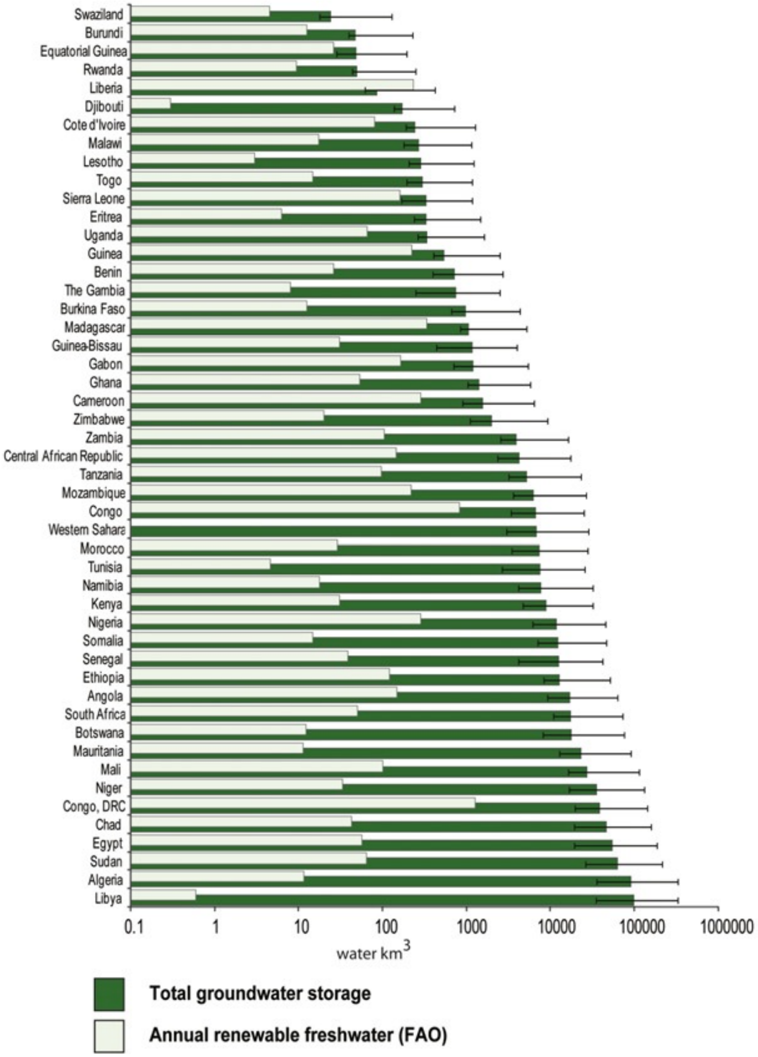
Groundwater storage for Africa based on the effective porosity and saturated aquifer thickness (MacDonald et al., 2012: Environ Res. Lett.)





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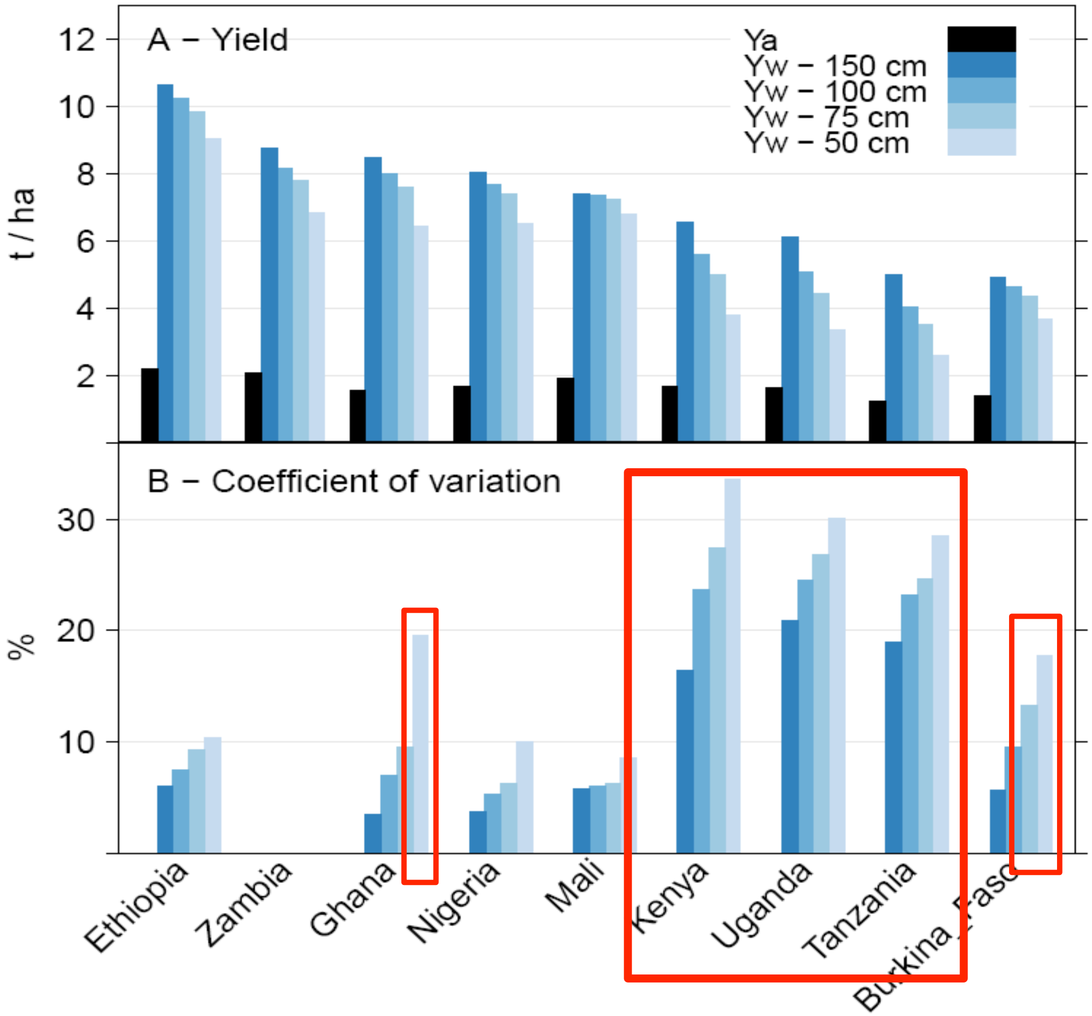
Where would investment in irrigation have greatest payoffs for cereal production in Sub-Saharan Africa?



These figures show simulated rainfed maize yield potential in 9 African countries as influenced by soil rooting depth, and the associated year-to-year variability (i.e. risk) in that yield as estimated by the coefficient of variation.

Areas with highly uncertain yields due to year-to-year variability in rainfall, as made worse by shallow soils, would benefit most from irrigation if there are sustainable sources of water supply

Source: Global Yield Gap Atlas, provided by Dr. Nicolas Guilpart

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Seminal importance of weather data

- **Weather data are an essential international public good and there is urgent need to establish a global public system of collection and access that is required to support sustainable intensification of crop and livestock production**
- **Danger of privatization of weather data collection and access if governments do not support it**

"As if we needed any more proof that the Big Data phenomenon is well and truly upon us, Monsanto has agreed to acquire the Climate Corp. for $930 million. The real stunner of a deal marks one of the largest buys of a new-era data analytics company."

Source: Bloomberg Business Week, 2 October 2014

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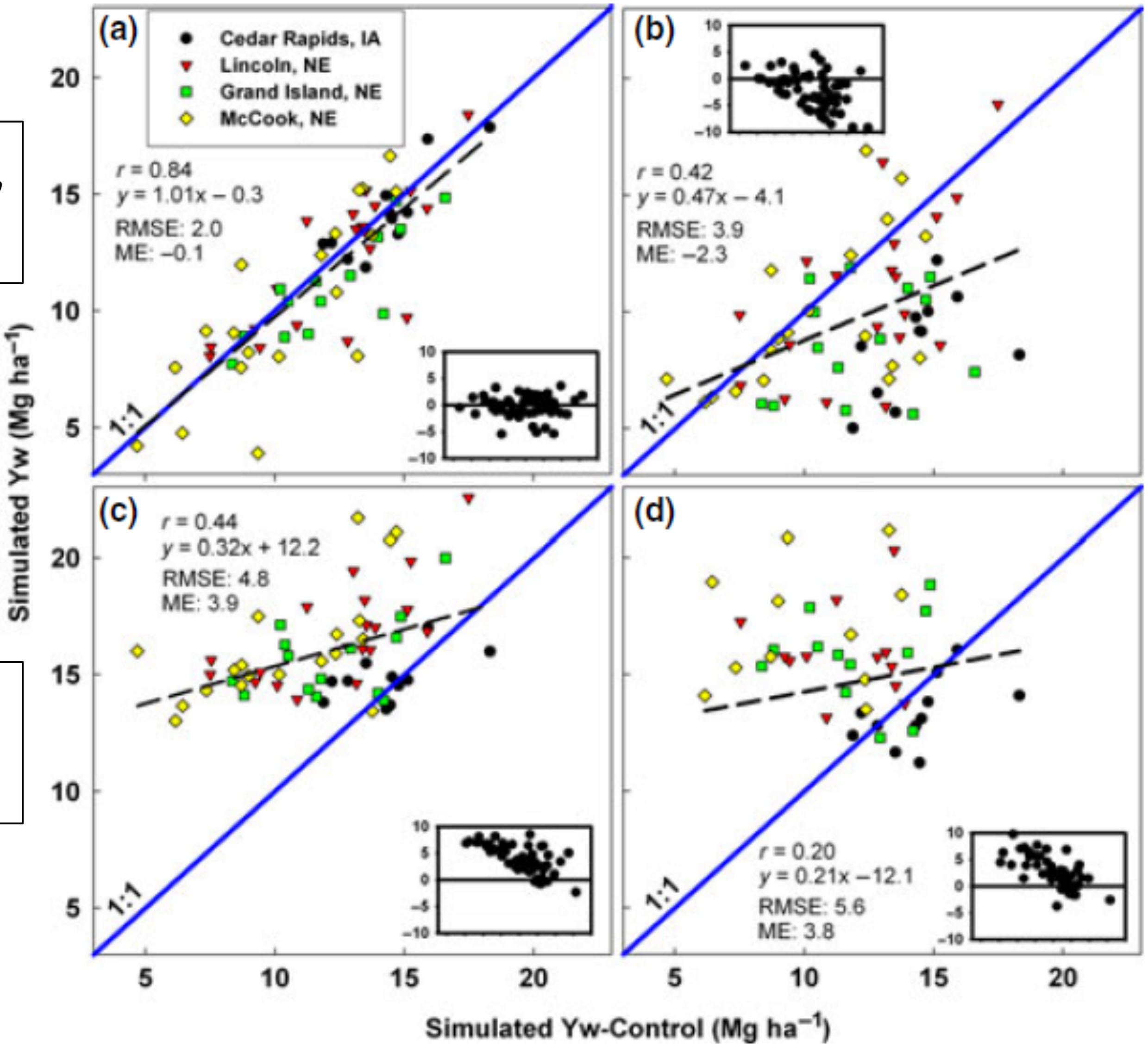
Simulating maize yields with different sources of weather data

Source: Van Wart et al. 2013, Global Change Biology

(a) NOAA, observed

(b) NCEP, gridded



(c) CRU, gridded

(d) NASA, gridded

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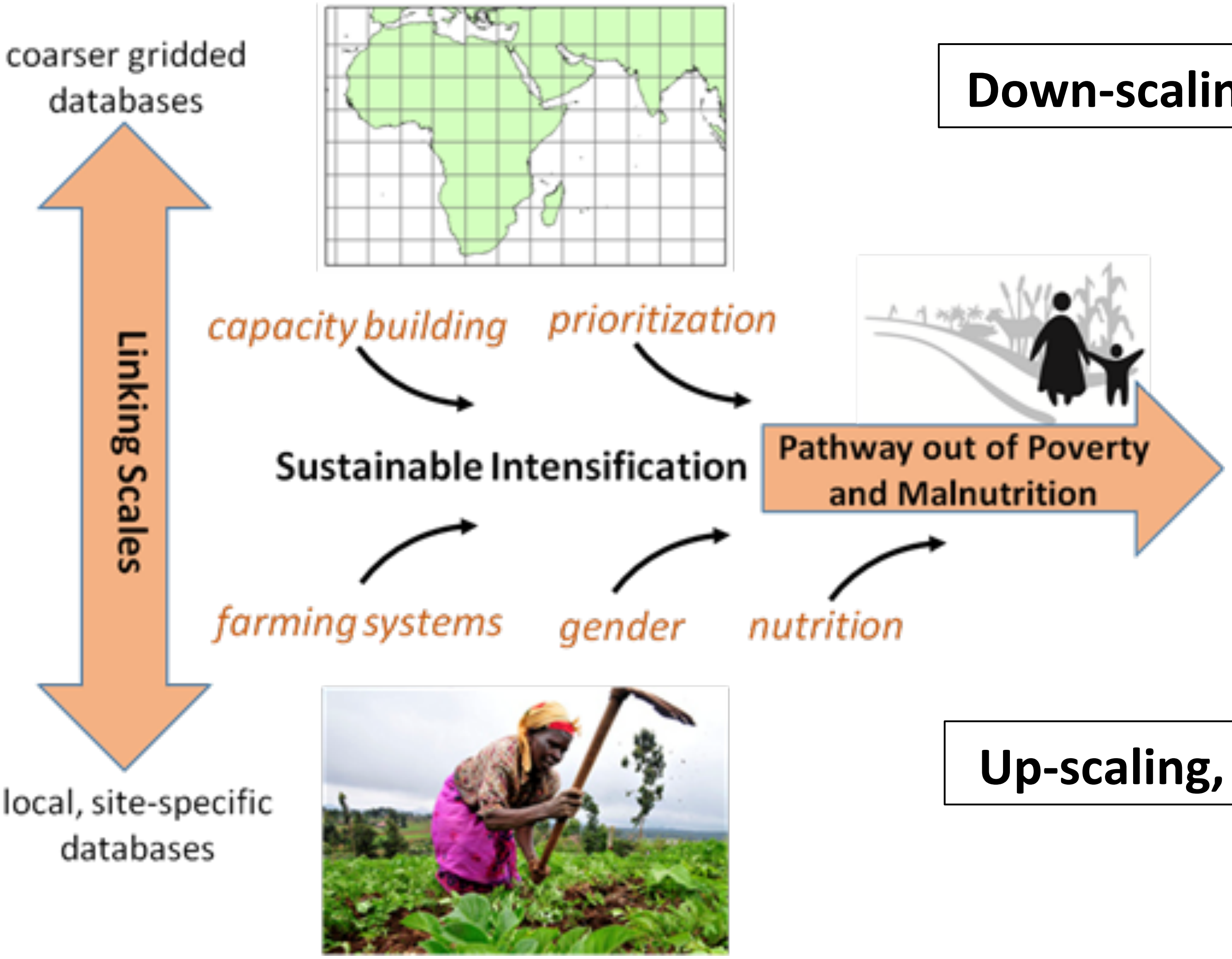
Big Data: Top-Down versus Bottom-Up



coarser gridded databases

Linking Scales

local, site-specific databases

capacity building

prioritization

Sustainable Intensification

Pathway out of Poverty and Malnutrition

farming systems

gender

nutrition

Down-scaling, “top-down”

Up-scaling, “bottom-down”

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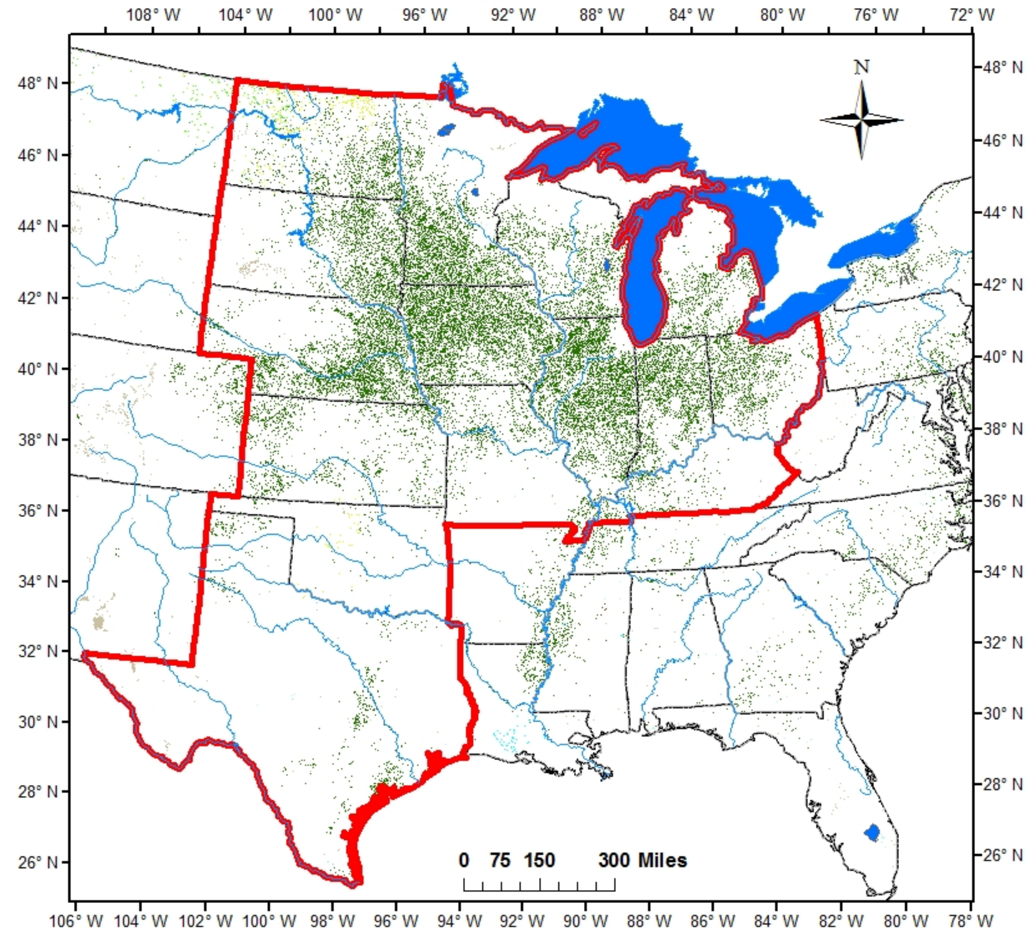
USA Maize Production: Harvested Hectares

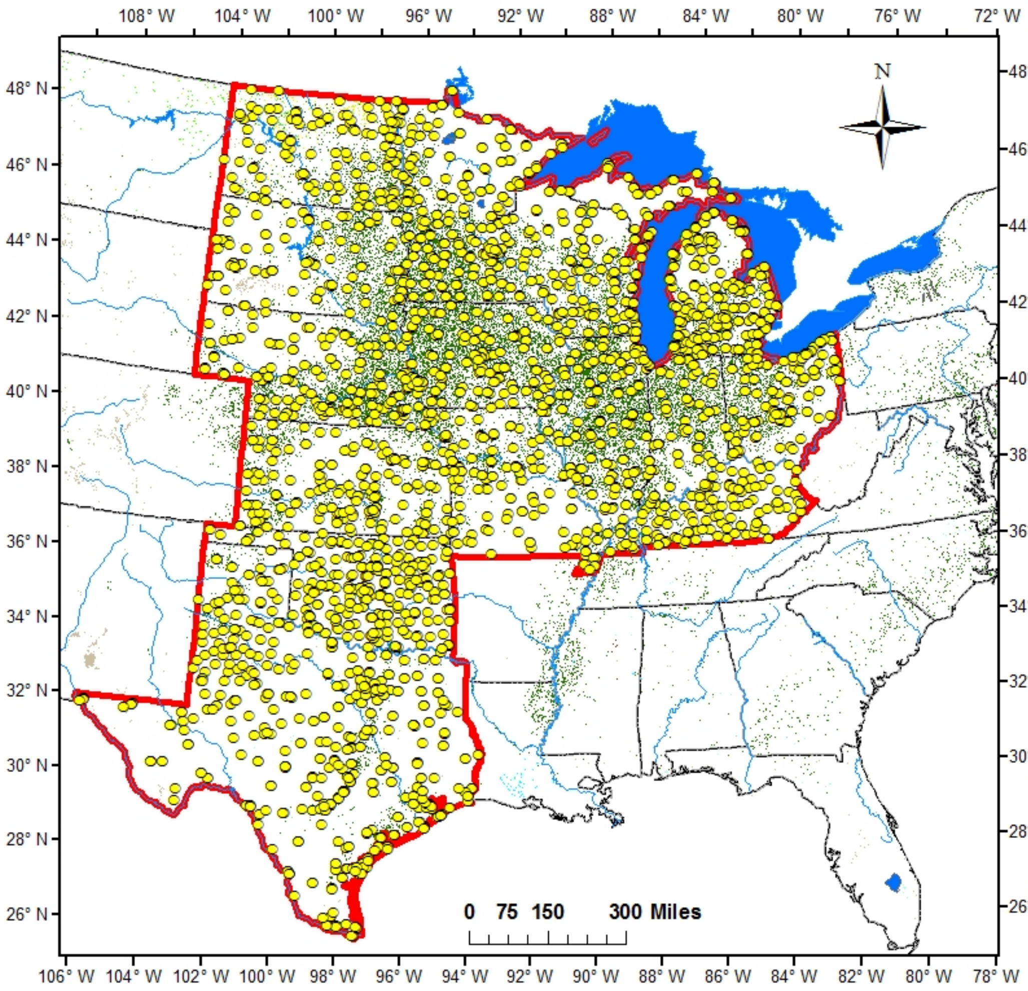


<u>Corn belt and Great Plains</u>:

IA, KS, IL, IN, KY, MN, MI, MO, NE, ND, OH, OK, SD, TX, WI (delimited by red line)

These 15 states account for >90% of USA maize area and total production

All weather stations with daily data (n=2825)



Both NOAA and MESONET:

- *National Oceanic and Atmospheric Administration* (NOAA): Stations are typically located in cities and airports and only record daily temperature and precipitation
- *State MESONET* systems: Developed for agriculture and located in agricultural areas with all required variables for crop simulation (daily radiation, temperature, precip, humidity, wind speed)

Courtesy of: F. J. Morell, Univ. of Nebraska

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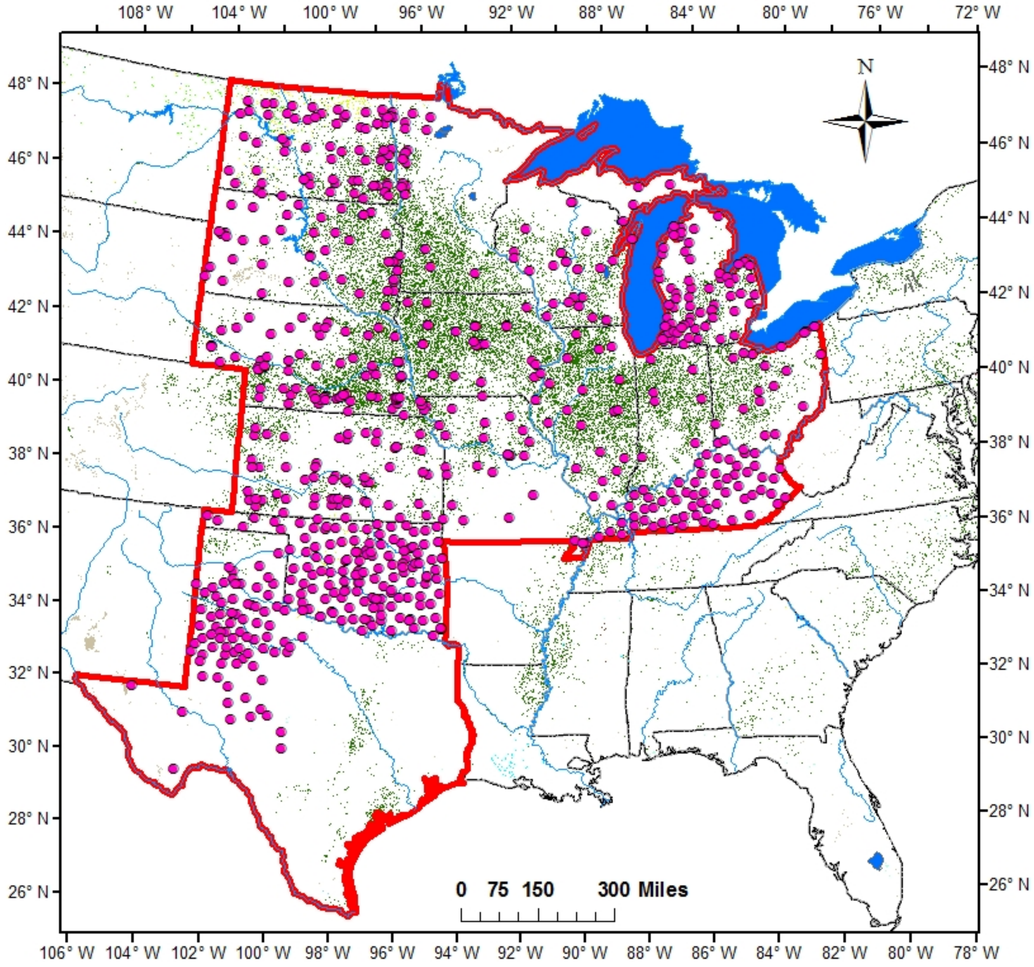
All MESONET stations with daily data

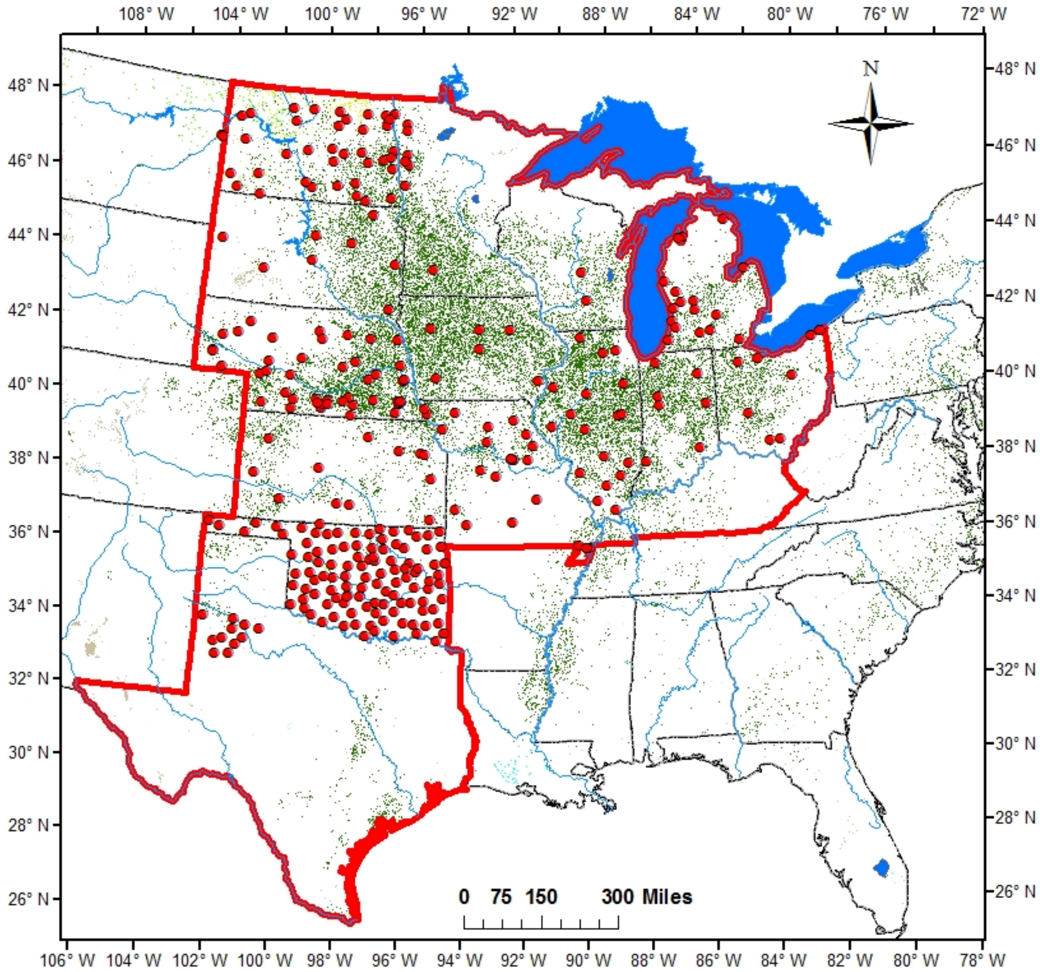


<u>State MESONET stations</u>:

- Spatial density and coverage varies by state
- Total of 747 stations
- Many of these stations are no longer active, or do not have more than 15-years of daily records

Courtesy of: F. J. Morell, Univ. of Nebraska

Active MESONET stations with >15 years data

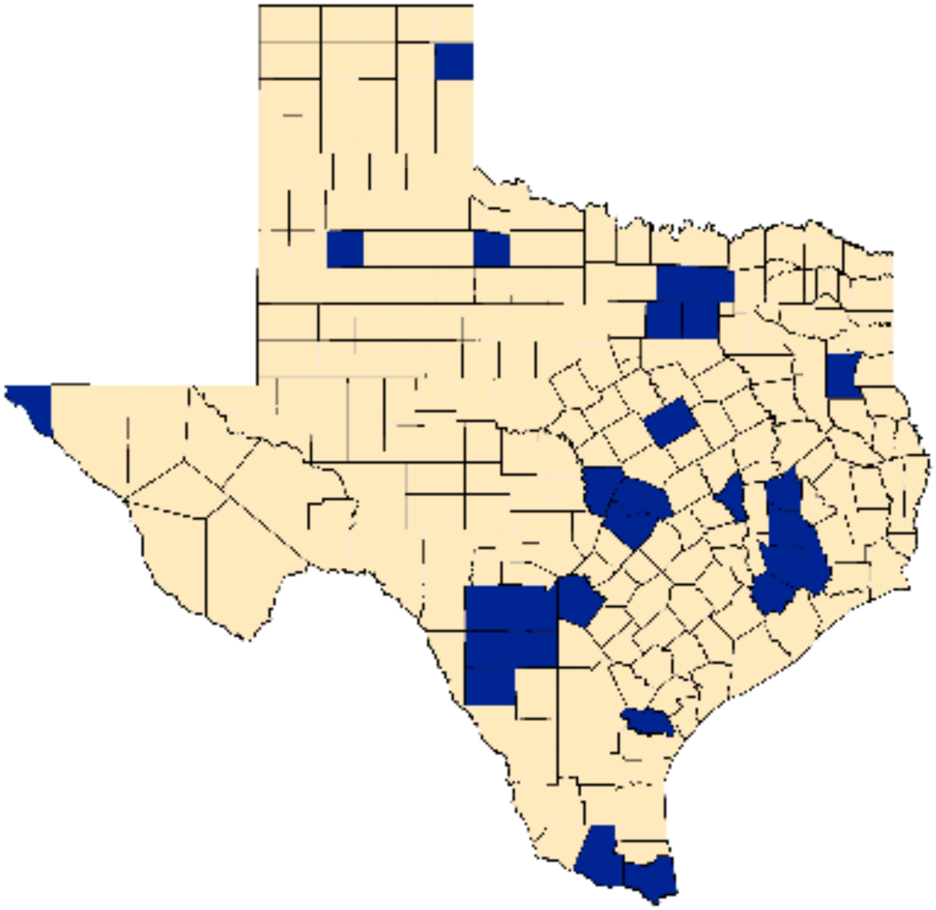


<u>**Spatial Coverage by state**</u>:

- **316 stations total**
- **Only *Oklahoma* has excellent coverage**
- **Three states have reasonable coverage (IL, NE, ND)**
- **Most states have poor coverage (IA, IN, KS, KY, OH, MI, MN, MO, SD)**

Courtesy of: F. J. Morell, Univ. of Nebraska

In absence of publicly-available weather data…..



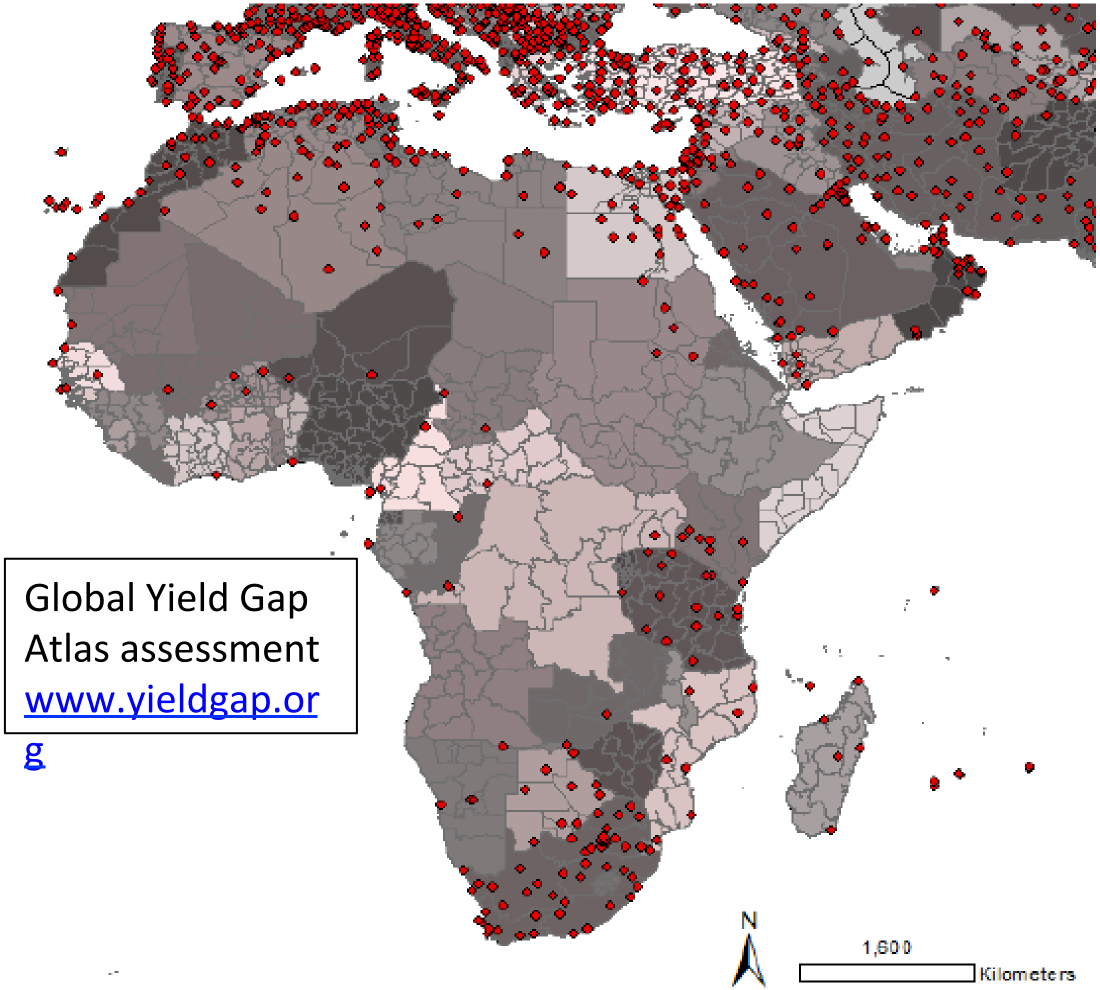
Weather data for sale:

- Texas counties in which weather data relevant for agriculture can be purchased from privately owned weather-station networks
- Sometimes simulated, sometimes observed, not transparent

Courtesy of: F. J. Morell, Univ. of Nebraska

Weather-data black holes in many low-income developing countries

Weather stations with <30 days missing in 2008



Global Yield Gap Atlas assessment www.yieldgap.org

In a world threatened by climate change, there is a critical need for good quality, publicly available weather data relevant for crop production:

-- Daily time step

-- Real-time and long-term (+20-yrs minimum)

Both for developed and developing countries!!

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Seminal Role of Big, Open Weather Data

- Help farmers make better management and marketing decisions
- Develop robust metrics to quantify environmental performance (e.g. impact on water quality, biodiversity, greenhouse gas emissions, soil quality, farm worker health, etc)
- More effectively prioritize R & D and technology transfer
- Adapt/mitigate climate change, and other environmental issues
- Inform policies to help countries develop appropriate food security and land-use strategies

The bottom line:

☐ critical need to get going on acquiring the required data

☐ Good news! the cost of acquiring the required data, with adequate spatial coverage is modest and steadily decreasing due to advances in knowledge and technologies to acquire it

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Global Yield Gap Atlas

Water for Food
Robert B. Daugherty Institute
University of Nebraska

Big Picture: Dealing With Climate Change

- Nearly all future climates with potential to produce food exist somewhere in the world today
- Learning how farmers currently deal with today's harsh and variable climates provide important insight and understanding on how to mitigate risk and <u>continue to raise yields</u> in the face of climate change
  - Publicly accessible databases, information technologies, improved simulation models, decision-support tools, agronomic management options, and crop and livestock genetic improvement for these climates will be the foundation for dealing with increased risk and uncertainty

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Global Yield Gap Atlas

Water for Food
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Food security and environmental conservation are two of the greatest challenges facing the world today. It is predicted that food production must increase by at least 70% before 2050 to support continued population growth, though the size of the world's agricultural area will remain essentially unchanged.

This updated and thoroughly revised Second Edition provides in-depth coverage of the impact of environmental conditions and management on crops, resource requirements for productivity, and effects on soil resources. The approach is explanatory and integrative, with a firm basis in environmental physics, soils, physiology, and morphology. System concepts are explored in detail throughout the book, giving emphasis to quantitative approaches, management strategies and tactics employed by farmers, and associated environmental issues.

Drawing on key examples and highlighting the role of science, technology and economic conditions in determining management strategies, this book is suitable for agriculturalists, ecologists, and environmental scientists.

D. J. Connor is Emeritus Professor of Agriculture at The University of Melbourne, Australia. His research programs deal with land and environmental relationships of a range of irrigated and rain fed cropping systems. In 2003 he was awarded the Donald Medal for outstanding contributions by the Australian Society of Agronomy.

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K. G. Cassman is Professor of Agronomy at the University of Nebraska, USA. His research focuses on nutrient cycling and crop nutrient requirements, crop yield potential, and water productivity of irrigated crops. In 2006 he received the Agronomic Research Award from the American Society of Agronomy.

From reviews of the first edition:

"... a good introduction to almost all areas of the scientific basis of crop ecology, production, and management." *Times Higher Education Supplement*

"... an encyclopaedic survey of the environmental, genetical and physiological influences on crop production." *D. S. H. Drennan, Experimental Agriculture*

Cover illustration (*front*): ancient cereal landscape, Soria, Spain. © D. Connor; (back, left): women transplanting rice, Mauritania. © H. Gómez Macpherson; (*back, right*): Soybean harvest, Brazil. © D. Connor.

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Connor, Loomis and Cassman

CROP ECOLOGY

SECOND EDITION

CAMBRIDGE

CROP ECOLOGY

Productivity and Management in Agricultural Systems

SECOND EDITION

David J. Connor, Robert S. Loomis and Kenneth G. Cassman

CAMBRIDGE

Can irrigated crop production systems be sustainable, or is it an oxymoron? It must be sustainable!

- Water withdrawal does not exceed annually renewable supply of water, whether from surface or groundwater
- Water withdrawals have no negative impact on integrity of associated aquatic and terrestrial ecosystems
- Influence on water quality has no negative impact on human health
- Use of irrigation maintains or improves soil quality
- Water withdrawals have no negative impact on supply and quality of community water resources

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Land conversion accelerates climate change

- Increasing evidence linking clearing of Brazillian rainforest with increasing severity of droughts in San Paulo, hundreds of miles away:

"the rain forest's deforestation is starting to result in a fall of the abundant precipitation that sustains not only animals and plants but also farms and major urban centers hundreds of miles away"

"The situation is very bad, as bad as it can get before we go down the abyss"

Dr. Antonio Nobre, senior researcher at the National Institute of Space Research and the National Institute of Amazonian Research

From: Wall Street Journal, December 5, 2014

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YIELD PER UNIT LAND AND TIME IS A KEY METRIC

Crop yields in conventional and low-external input rotations:
Liebman et al, 2008: Agronomy Journal 100: 600-610¶

Rotation	Crop				Time in maize or soybean (% of total)
	Yr 1	Yr 2	Yr 3	Yr 4	
4-yr low external input	maize	soybean	oat-alfalfa	alfalfa	50
3-yr low external input	maize	soybean	oat-red clover	repeat	67
2-yr conventional	maize	soybean	maize	soybean	100

¶ No significant differences in yield of maize or soybean per crop, but there would be large differences in total maize and soybean produced among treatments on annual basis.

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