Representing crop management in CLM5

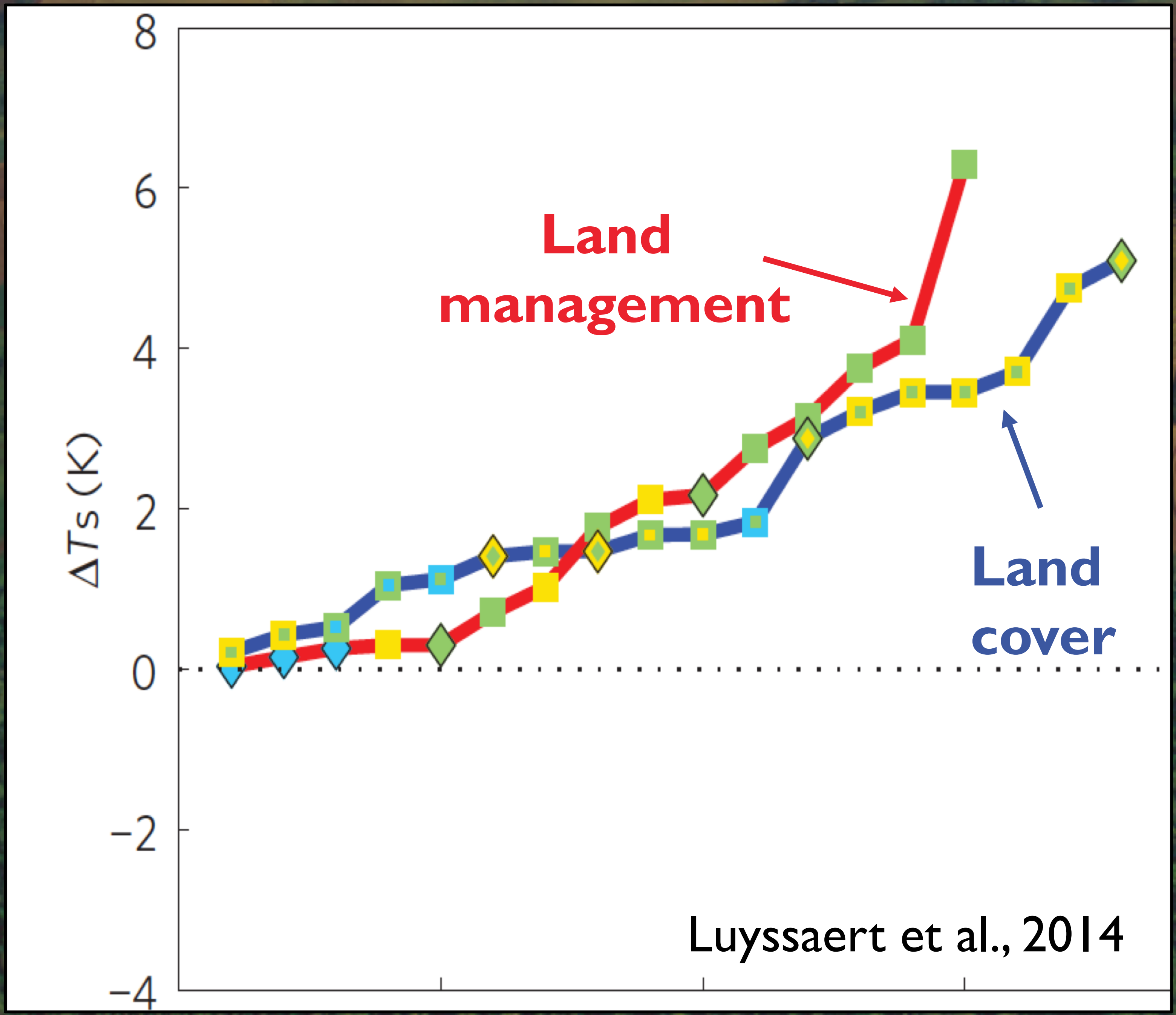
Danica Lombardozzi

Yaqiong Lu, Peter Lawrence, Dave Lawrence, Sean Swenson, Keith Oleson

2019 CTSM Tutorial

Agriculture provides food and also changes biogeophysical and biogeochemical properties of the land surface

Land management and land-cover change have impacts on surface temperature of similar magnitude



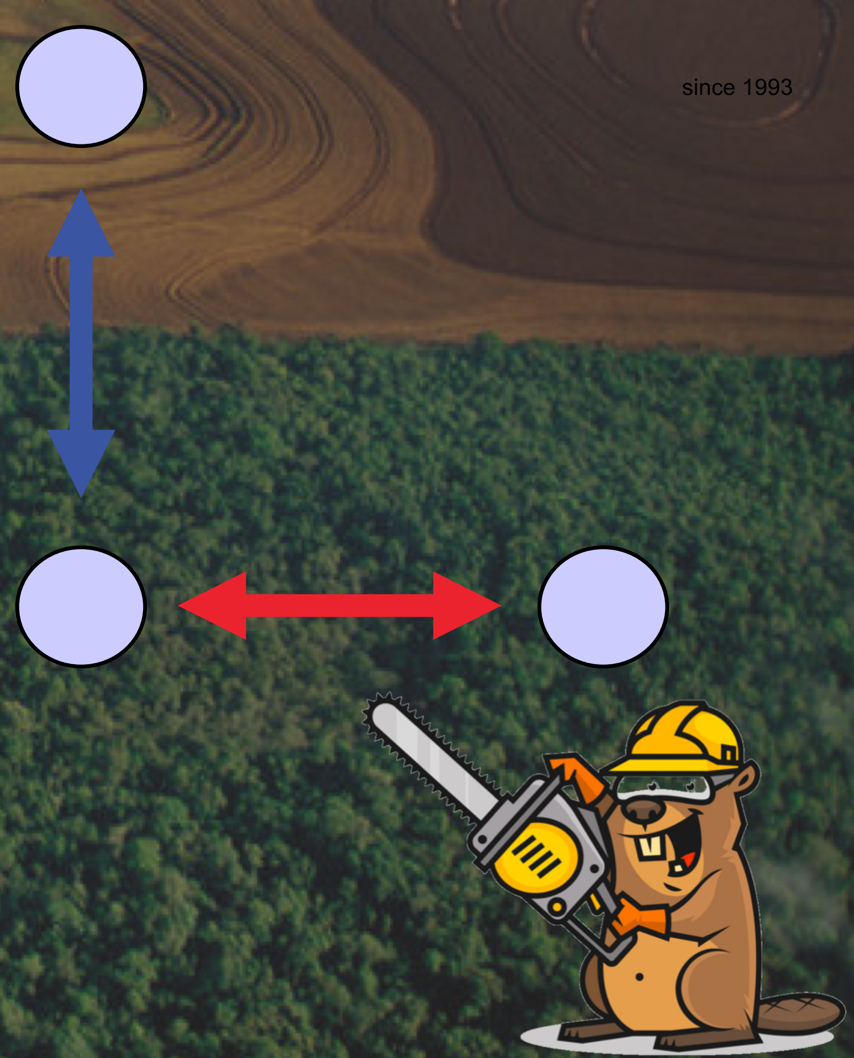
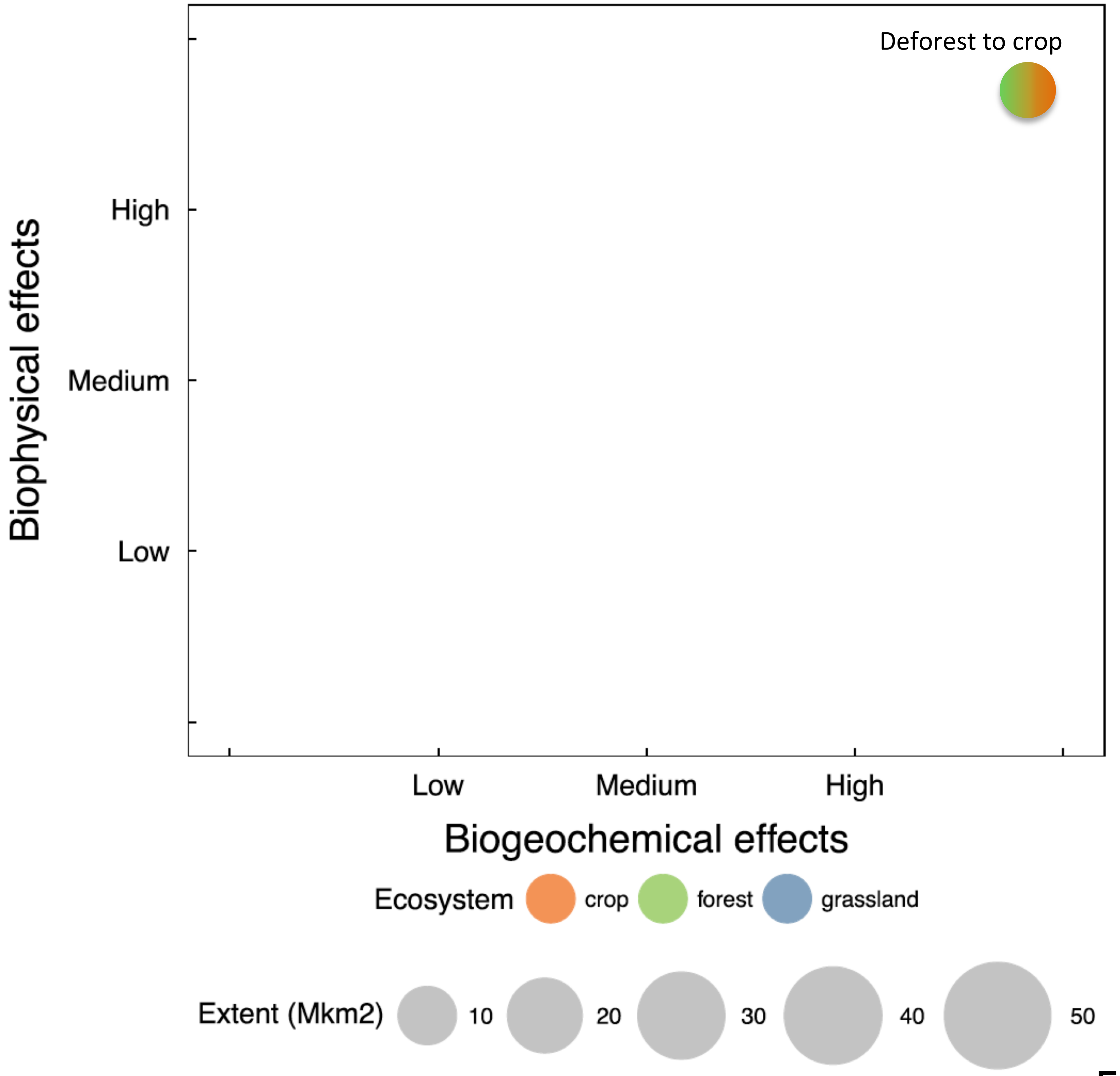


Image: Frans Lanting/Robert Harding Picture Library

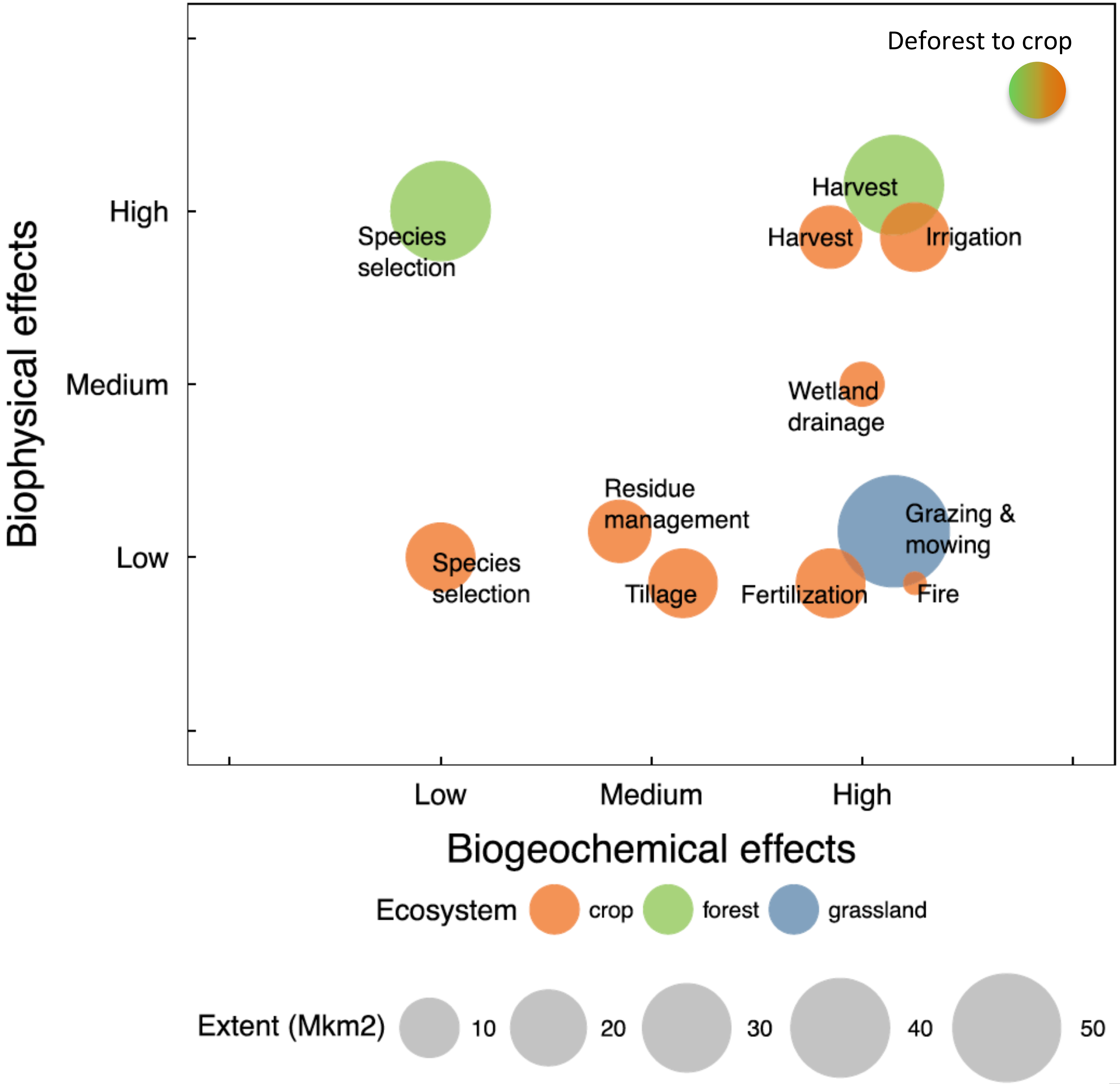
D. Lawrence

Synthesis of land management impacts



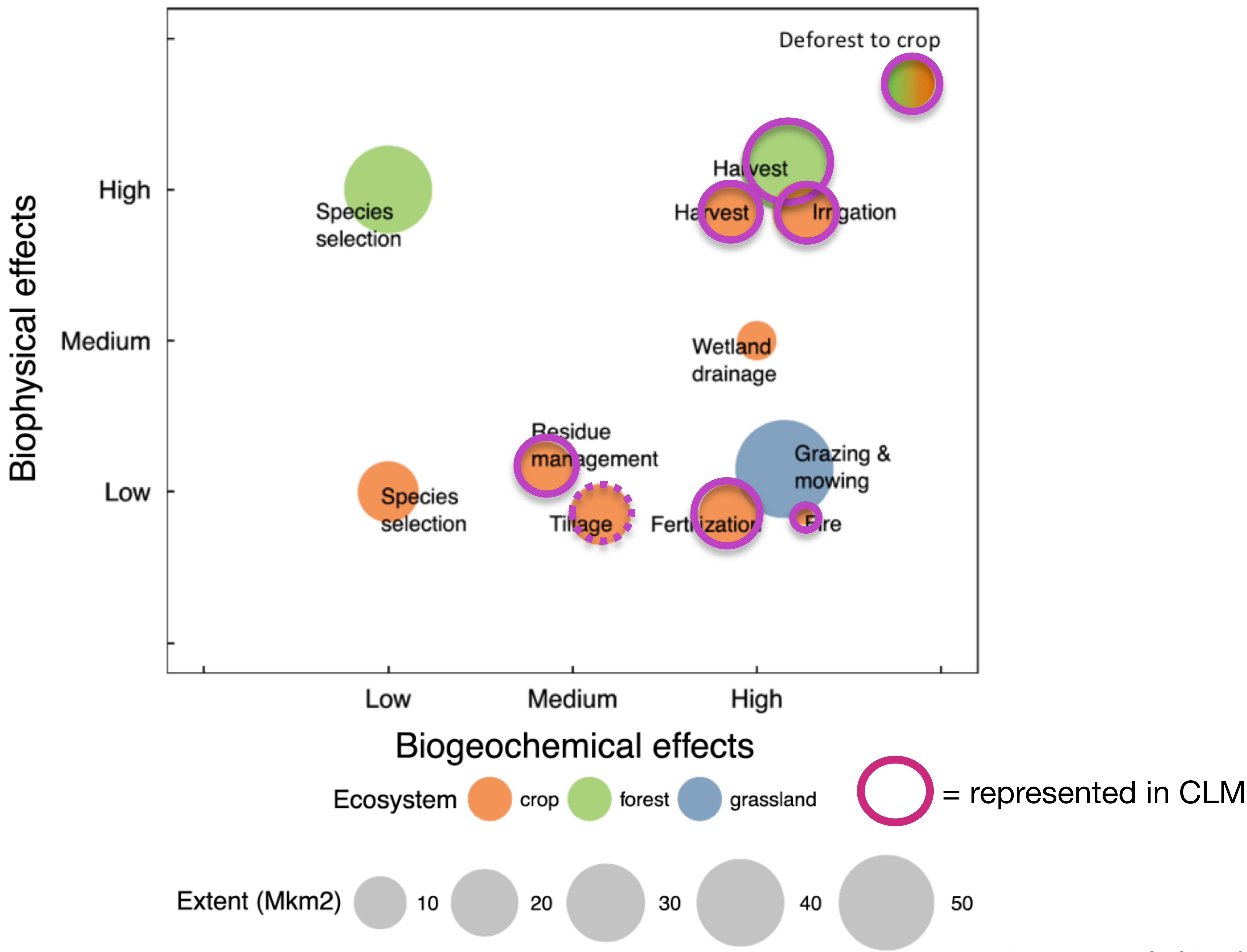
Erb et al., GCB, 2016

Synthesis of land management impacts



Erb et al., GCB, 2016

Land management in Community Land Model (CLM5)

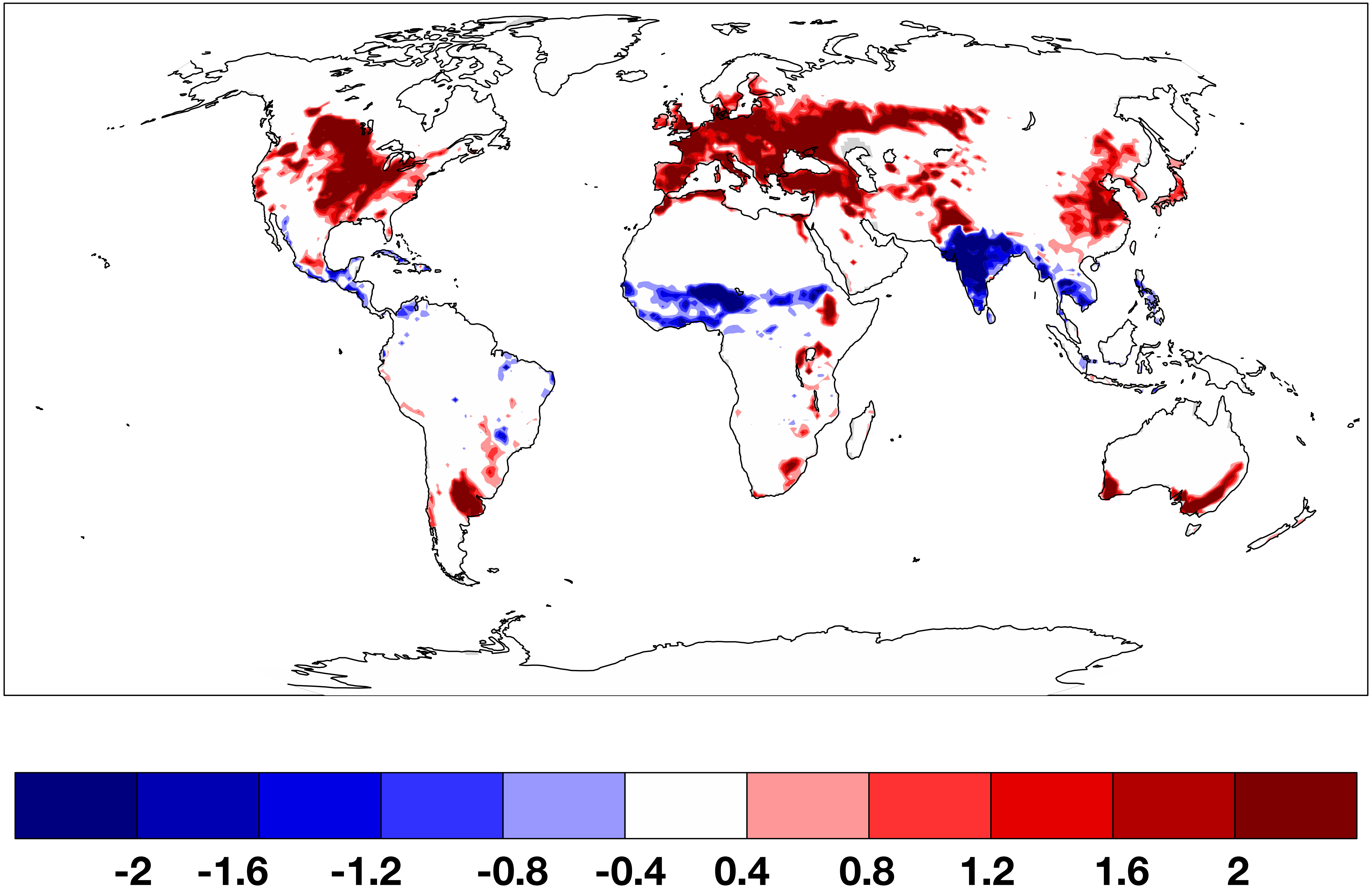


Erb et al., GCB, 2016

1991-2010 Average

Impact of Simulated Managed Crops

(relative to simulating generic crops)



Change in Annual Maximum Gross Primary Productivity (g C m^{-2} day^{-1})

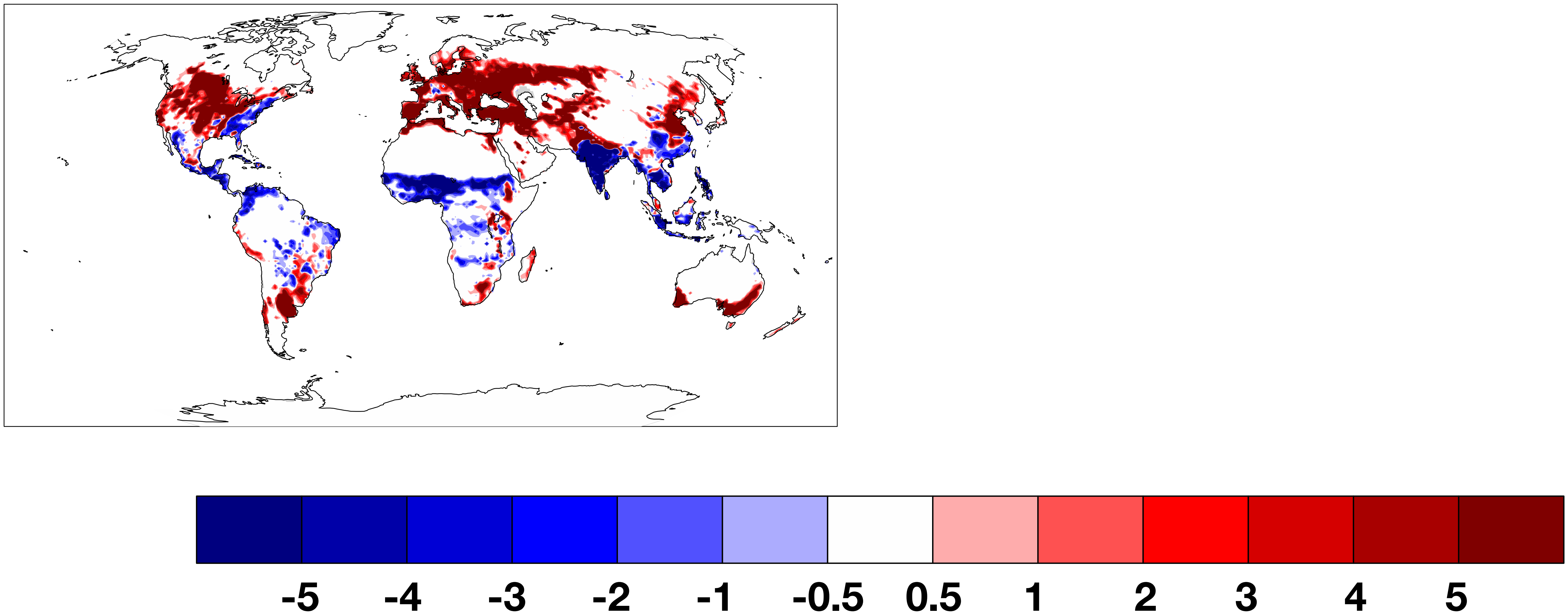
Lombardozzi et al., submitted

1991-2010 Average

Impact of Simulated Managed Crops

(relative to simulating generic crops)

Annual Monthly Maximum



Change in Latent Heat Flux (W m^{-2})

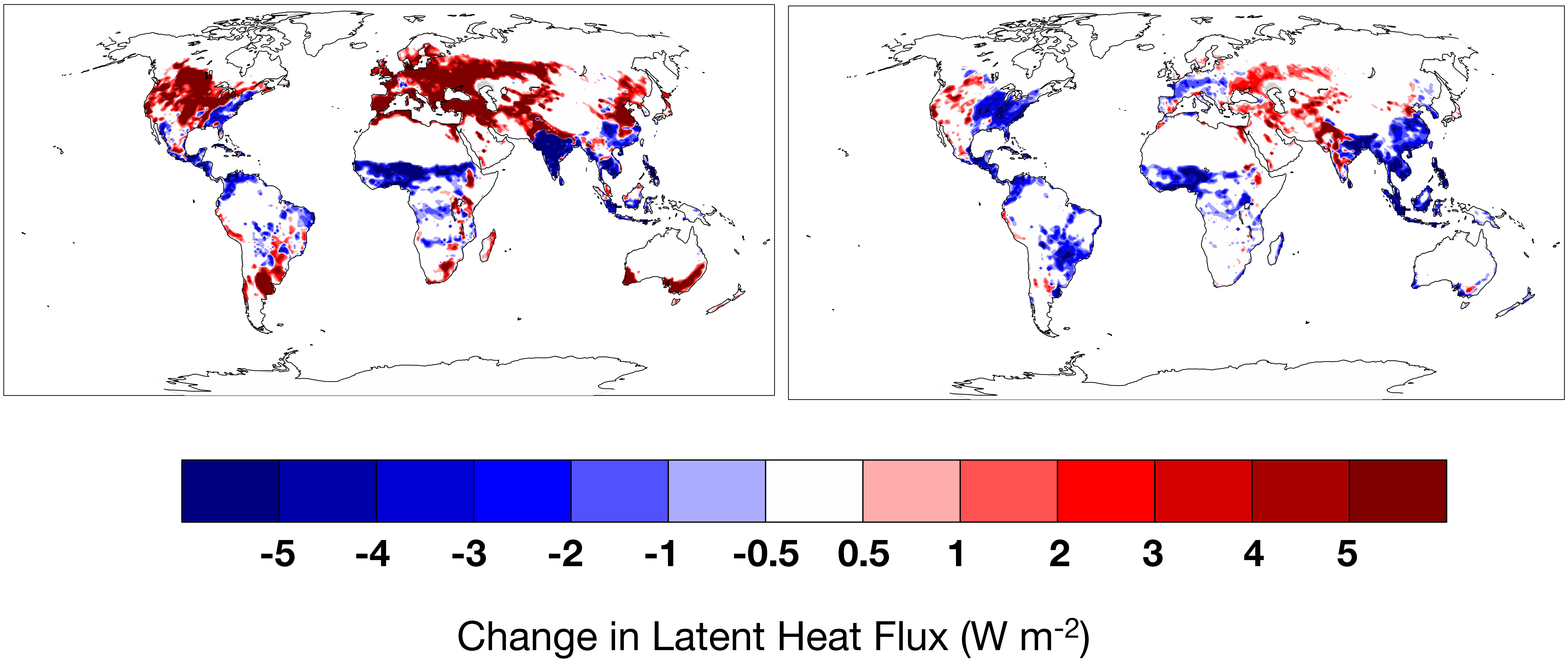
Lombardozzi et al., submitted

1991-2010 Average

Impact of Simulated Managed Crops

(relative to simulating generic crops)

Annual Monthly Maximum | **Annual Average**



Lombardozzi et al., submitted

History of the Crop Model

CLM4

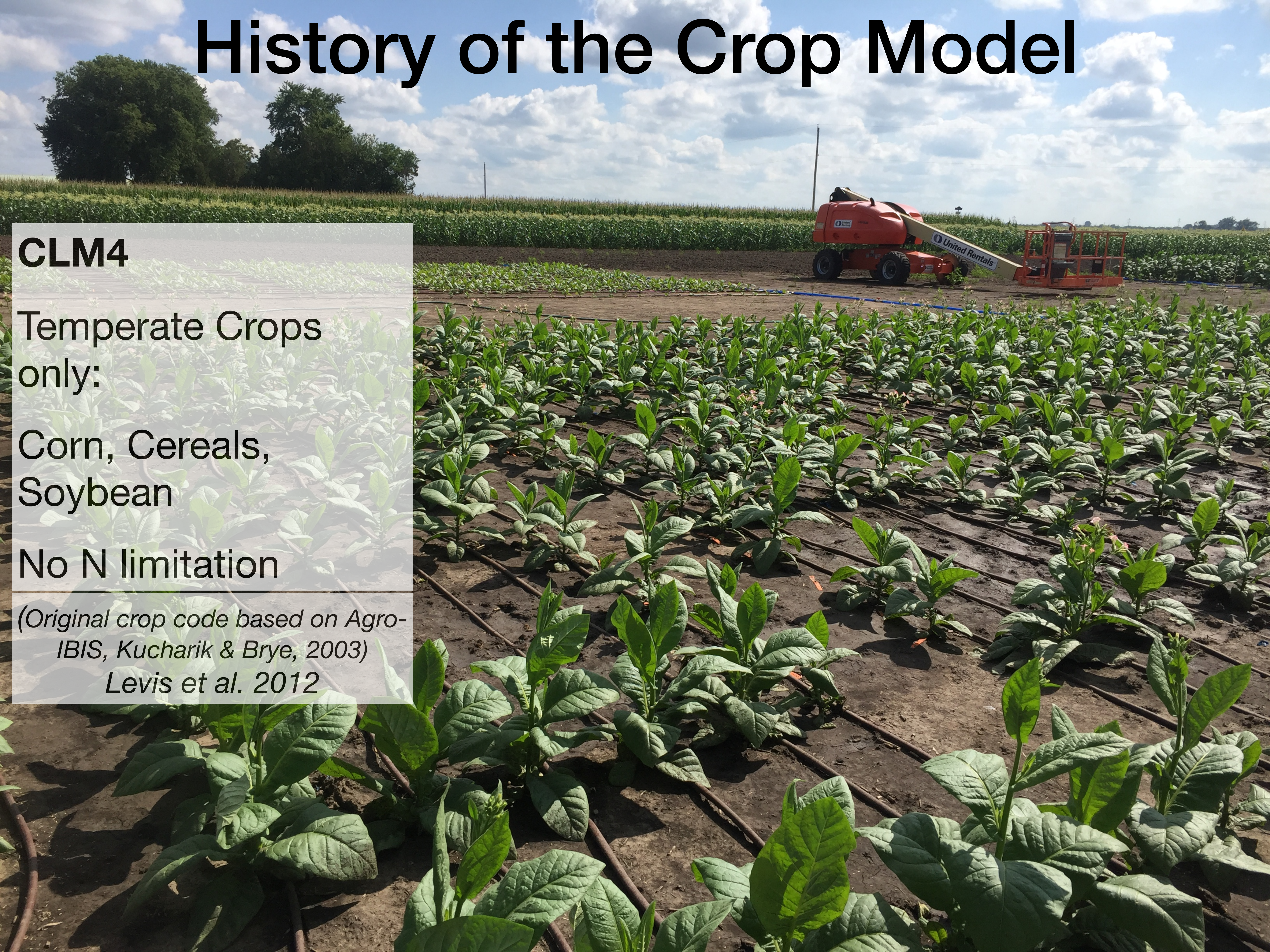
Temperate Crops only:

Corn, Cereals, Soybean

No N limitation

(Original crop code based on Agro-IBIS, Kucharik & Brye, 2003)

Levis et al. 2012



History of the Crop Model

CLM4	CLM4.5
Temperate Crops only: Corn, Cereals, Soybean No N limitation	Temperate Crops only Options to fertilize and irrigate Soybean N fixation
(Original crop code based on Agro-IBIS, Kucharik & Brye, 2003) *Levis et al. 2012*	*Levis et al. 2013; Drewniak et al. 2013*

History of the Crop Model

CLM4	CLM4.5	CLM5
Temperate Crops only: Corn, Cereals, Soybean No N limitation	Temperate Crops only Options to fertilize and irrigate Soybean N fixation	Added Tropical Crops: soy, sugarcane, rice, cotton Grain product pool Crop distributions through time
(Original crop code based on Agro-IBIS, Kucharik & Brye, 2003) *Levis et al. 2012*	*Levis et al. 2013; Drewniak et al. 2013*	*Levis et al. 2016; Lombardozzi et al, submitted*

History of the Crop Model

CLM4	CLM4.5	CLM5
Temperate Crops only:	Temperate Crops only	Added Tropical Crops: soy, sugarcane, rice, cotton
Corn, Cereals, Soybean	Options to fertilize and irrigate	Grain product pool
No N limitation	Soybean N fixation	Crop distributions through time
(Original crop code based on Agro-IBIS, Kucharik & Brye, 2003) *Levis et al. 2012*	*Levis et al. 2013; Drewniak et al. 2013*	*Levis et al. 2016; Lombardozzi et al, submitted*

Note: Crops are only active in the BGC configuration with component sets that specify "Crop" in the name (e.g., IHistClm50BgcCropG). All CESM CMIP6 simulations will include active crops.

Today's Objectives

1) Crop types and distributions
2) Crop phenology
3) Allocation in crops
4) Management options
5) Crop Yields
6) Ongoing & Future Developments

1) Crop Types & Distributions

Active Crop Types

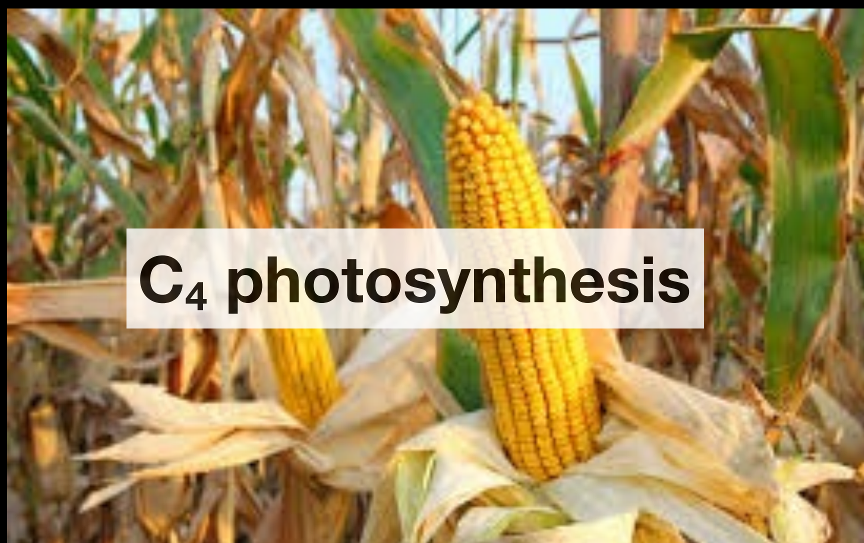
Corn* Spring Wheat Sugarcane

Soy* Cotton Rice

** Temperate and tropical varieties*

Active Crop Types

Corn*



Spring Wheat

Sugarcane

Soy*

Cotton

Rice

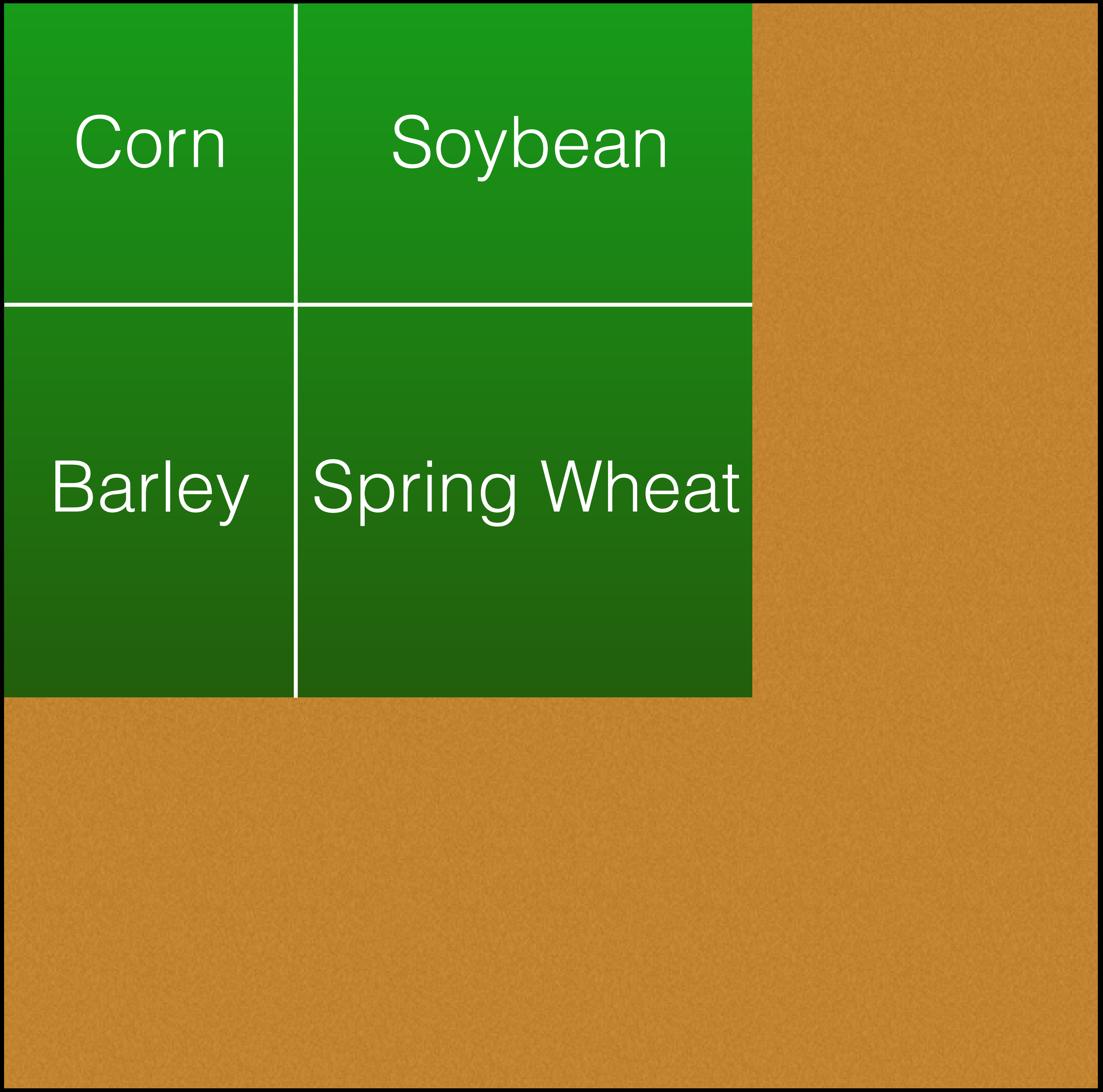
** Temperate and tropical varieties*

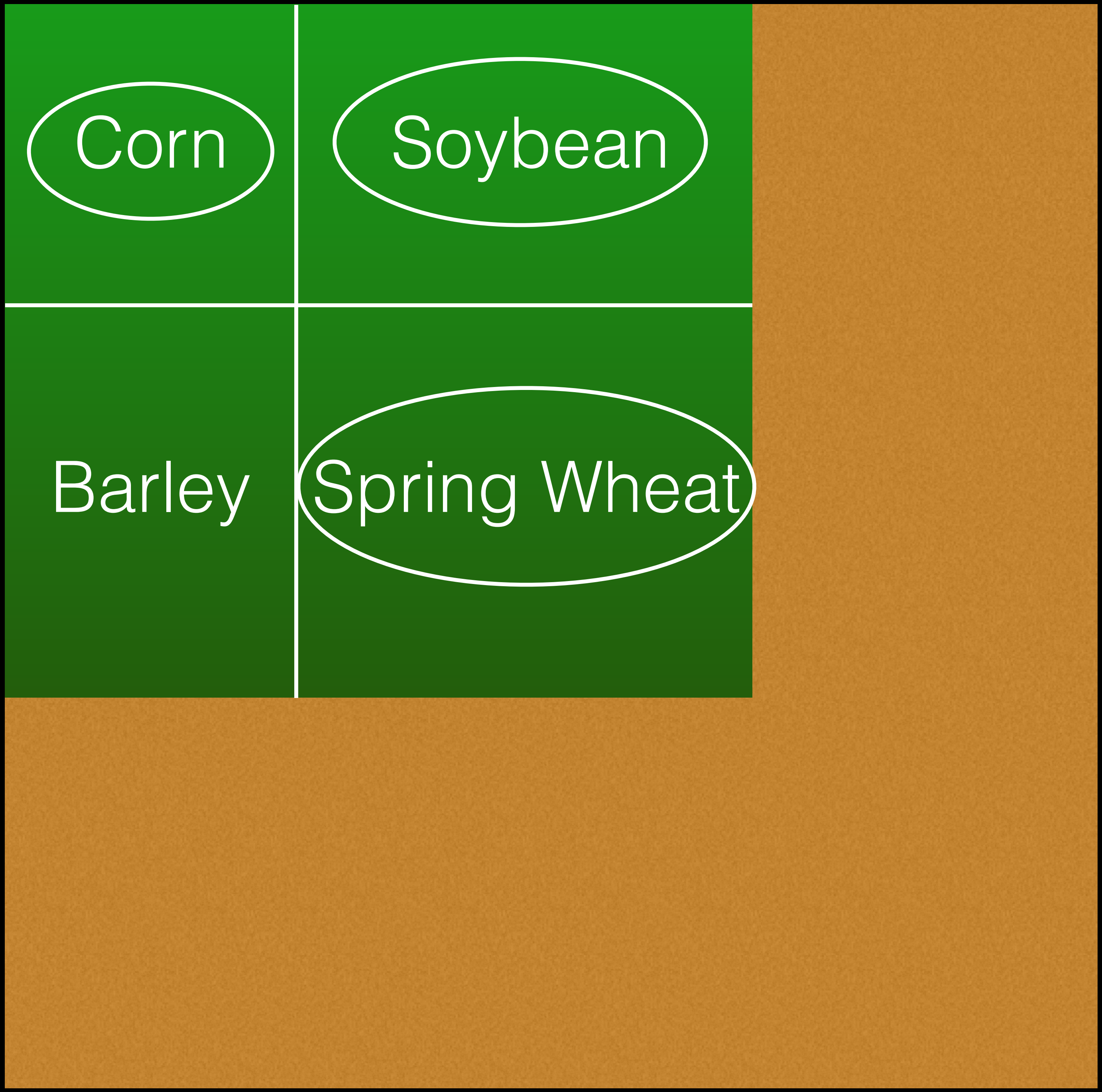
Additional Crops: Placeholders

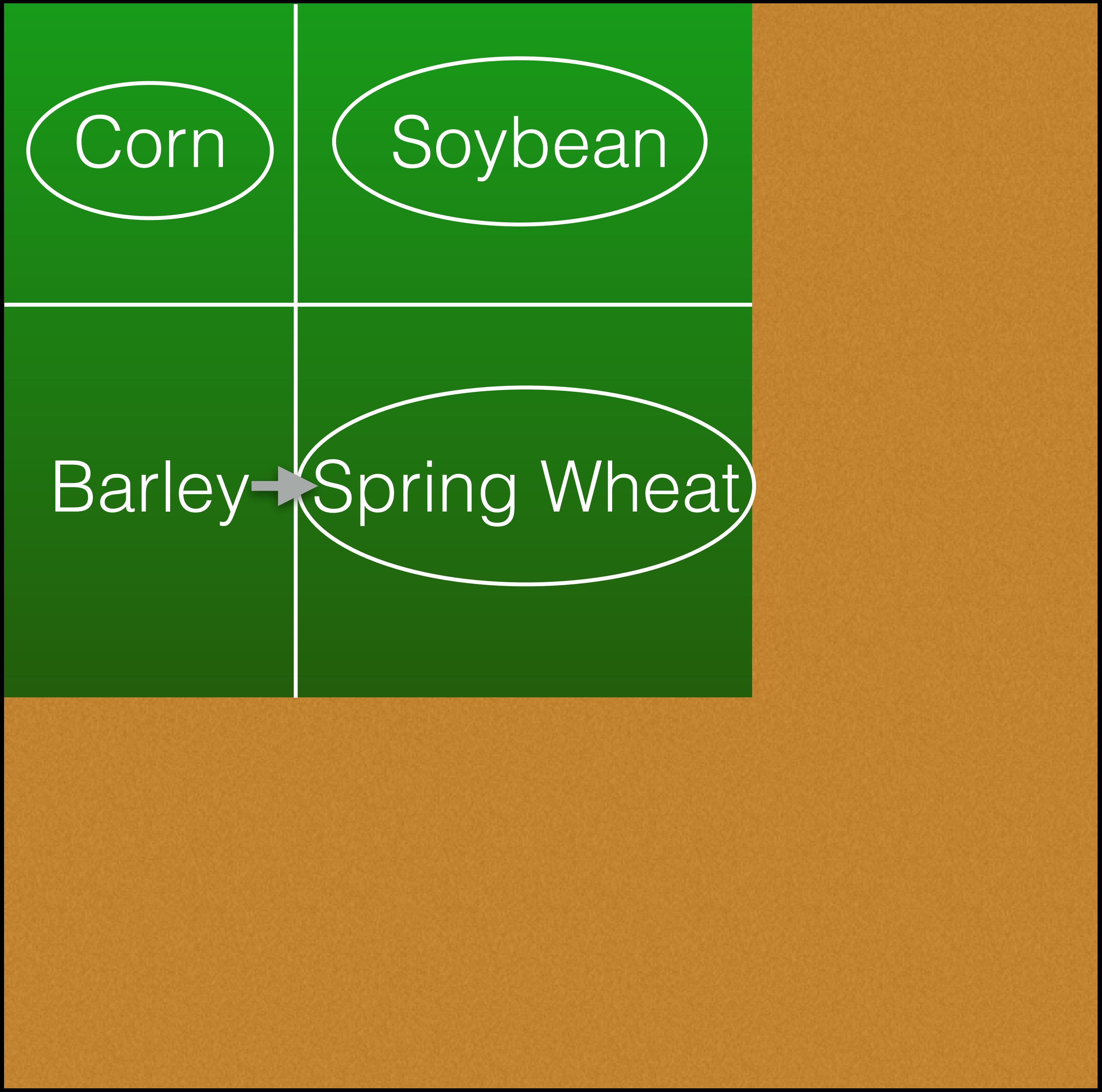
winter wheat
barley
winter barley
rye
winter rye
cassava
citrus
cocoa
coffee
date palm
fodder grass
grapes
groundnuts
millet
oil palm
potatoes
pulses
rapeseed
sorghum
sugarbeet
sunflower
miscanthus
switchgrass

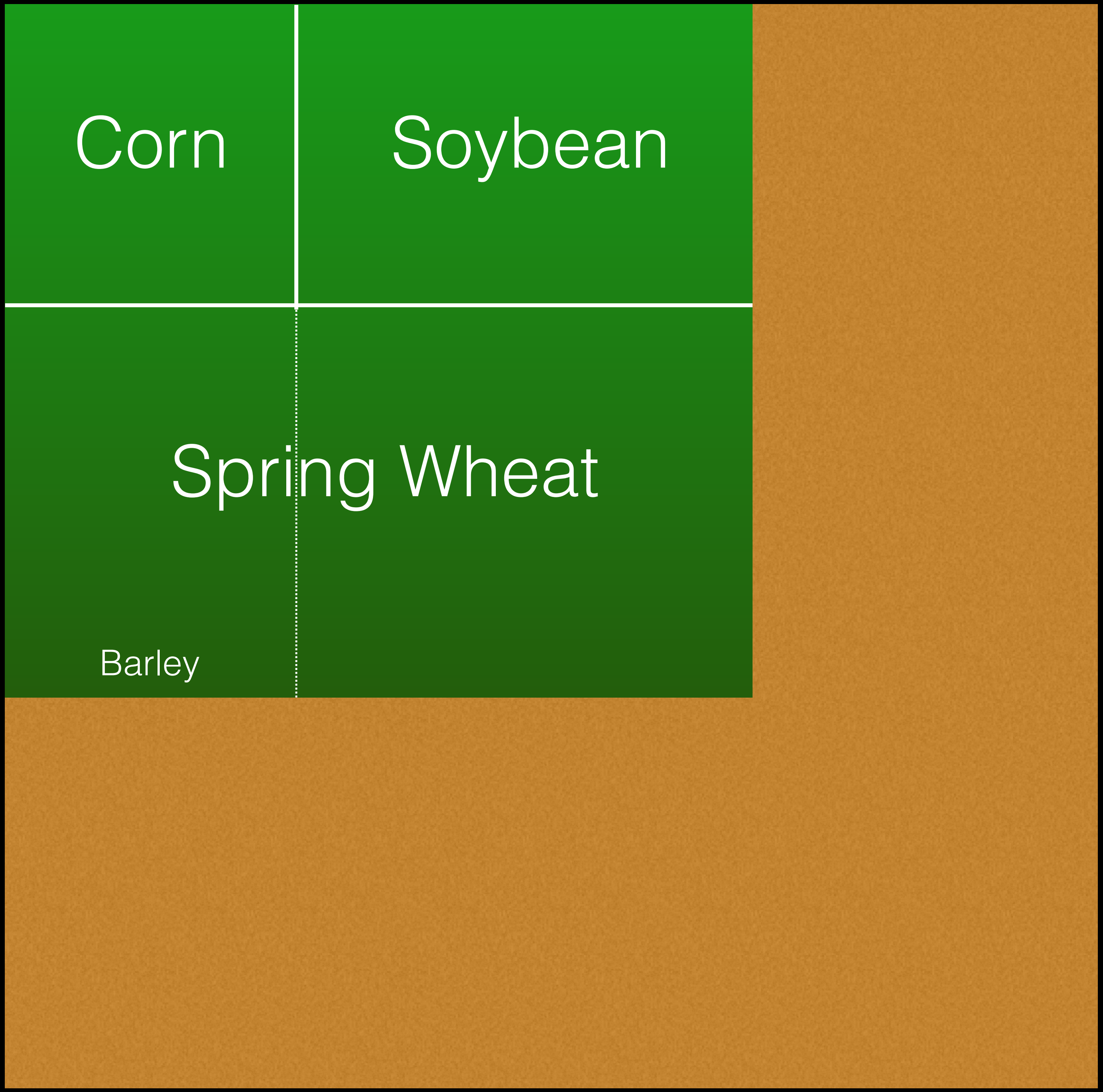
The surface dataset includes distributions for these crops, but we do not have the required parameters to represent them.

Note that there are irrigated and rain-fed PFTs for each crop type. When crops are active, the surface dataset has 78 (instead of 16) PFTs.


Corn
Soybean
Barley
Spring Wheat


Corn
Soybean
Barley
Spring Wheat


Corn
Soybean
Barley
Spring Wheat


Corn
Soybean
Spring Wheat
Barley

Yields can be calculated for 31 crop types

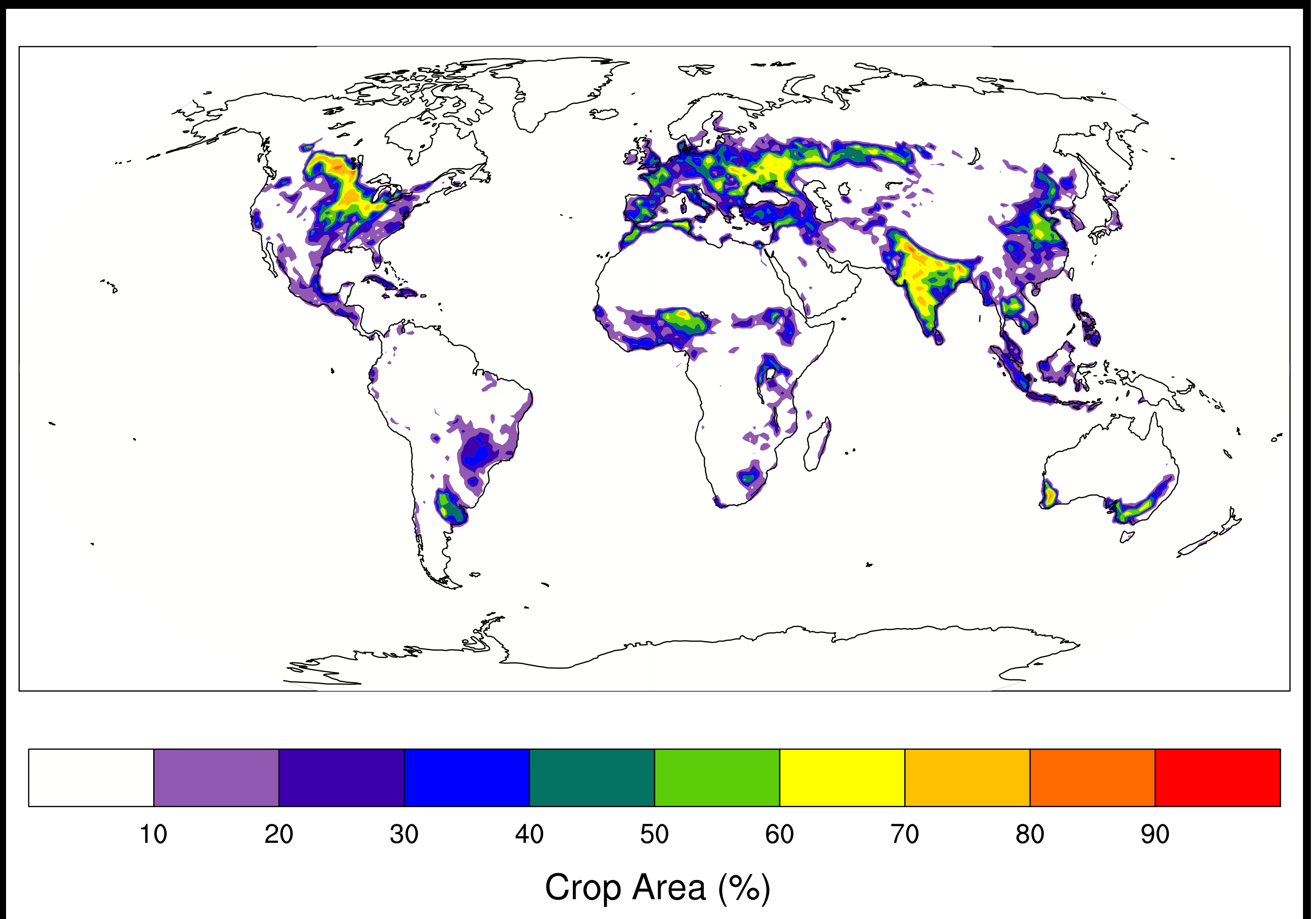
Assumption that inactive crops have same growing triggers & allocation as the active crop

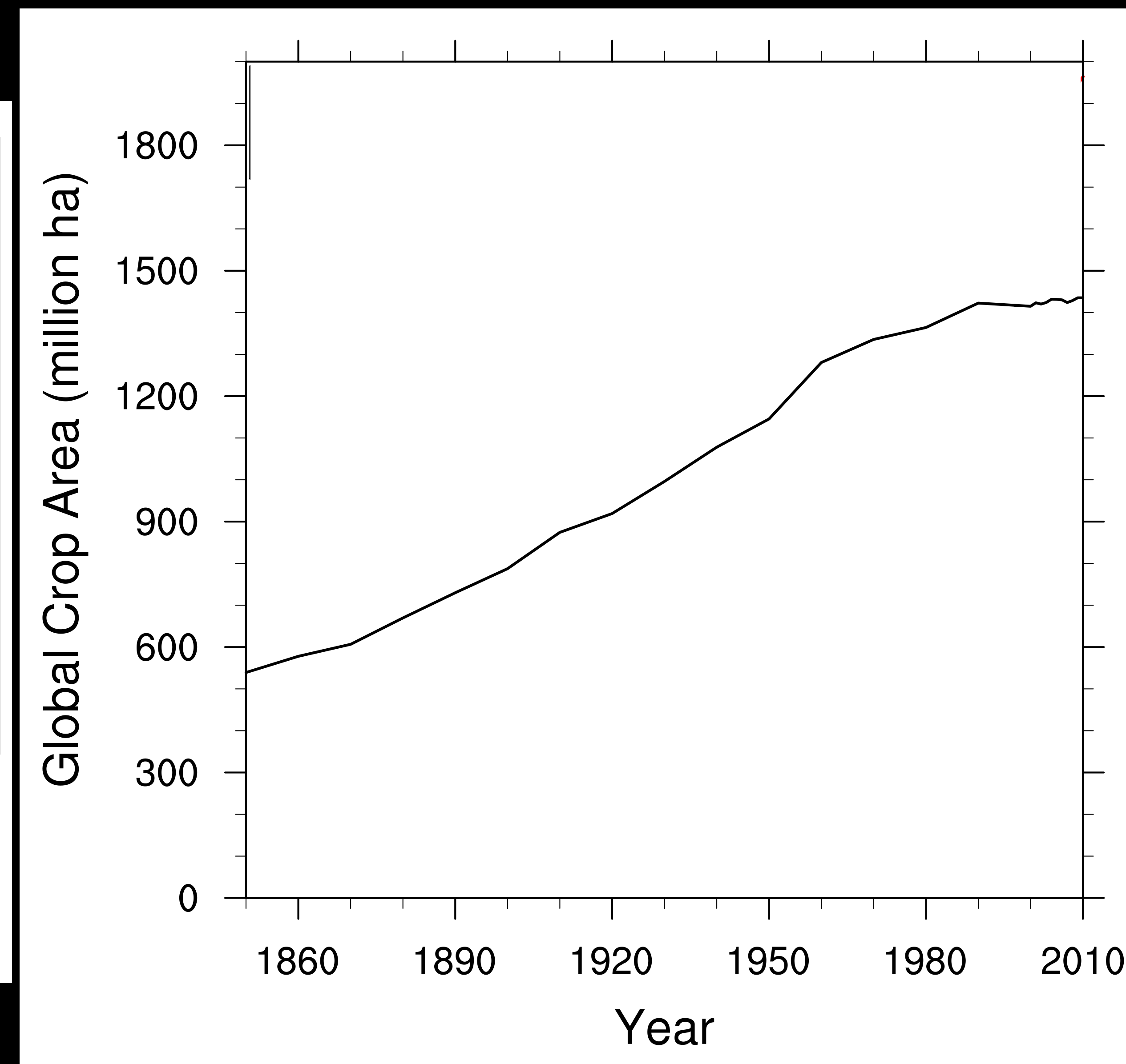
Need to use <u>surface dataset</u> for remapping during analysis

A full list of which parameters are used for each crop type is included in the CLM5 Tech Note

Crop Distributions

1991-2010 Crop Area





Crop distributions are found on the surface dataset ('fsurdat' in the clm namelist)


2) Crop Phenology
CNPhenology.F90

Phenology

1) Plant

Phase 1: Planting

Planting occurs **within the planting window** when a **10-day running mean 2-meter air temperature** reaches a crop-specific threshold (parameters listed in CLM5 Tech Note). Planting will occur at the end of the planting window if the T threshold is not met.

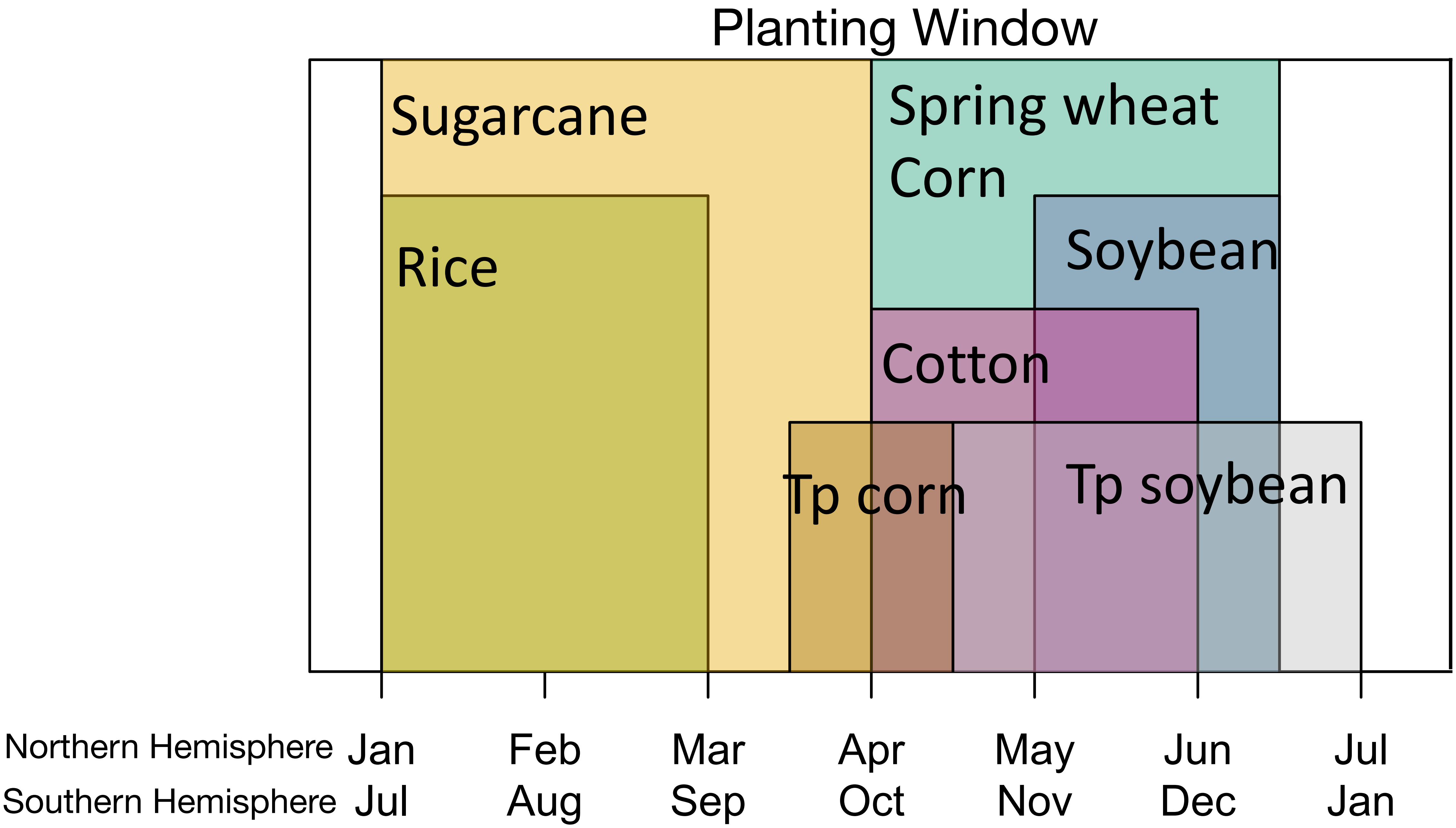


Figure from Yaqiong Lu

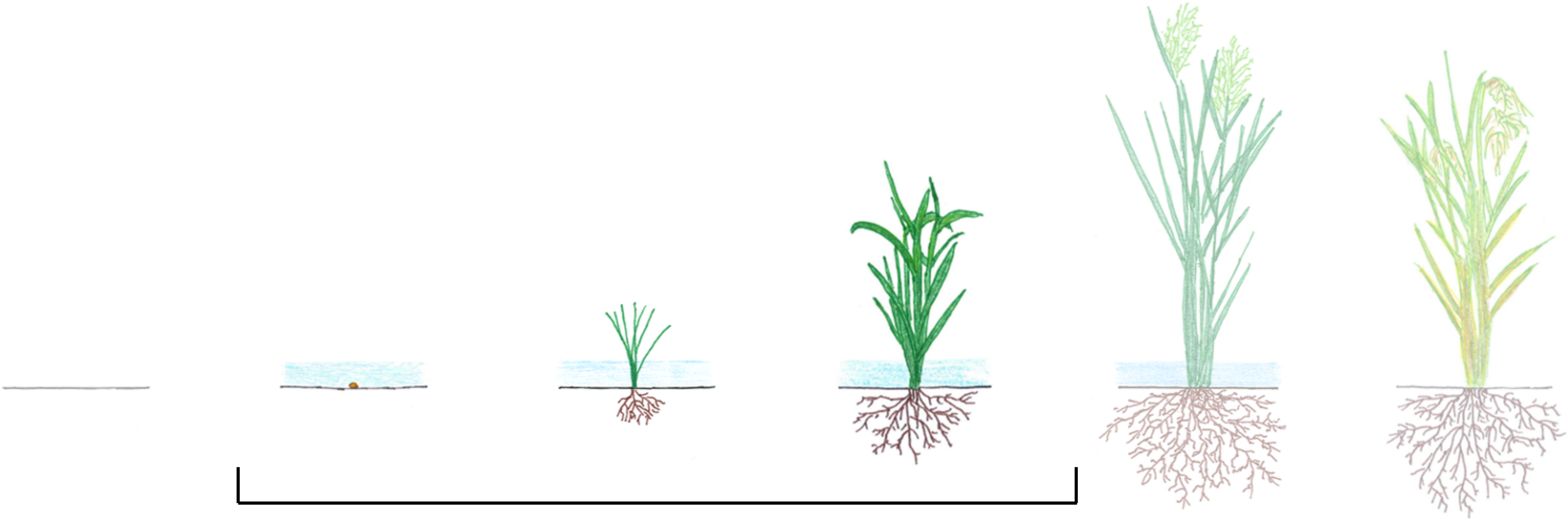
Phenology

1) Plant

2) Leaf Emergence

Phase 2: Leaf Emergence

Leaf emergence occurs when **soil temperature** reaches a crop-specific threshold (parameters listed in CLM5 Tech Note)



During leaf emergence, seed C is transferred to the leaf C pool and leaves continue to expand until they reach a crop-specific maximum leaf area index

Phenology

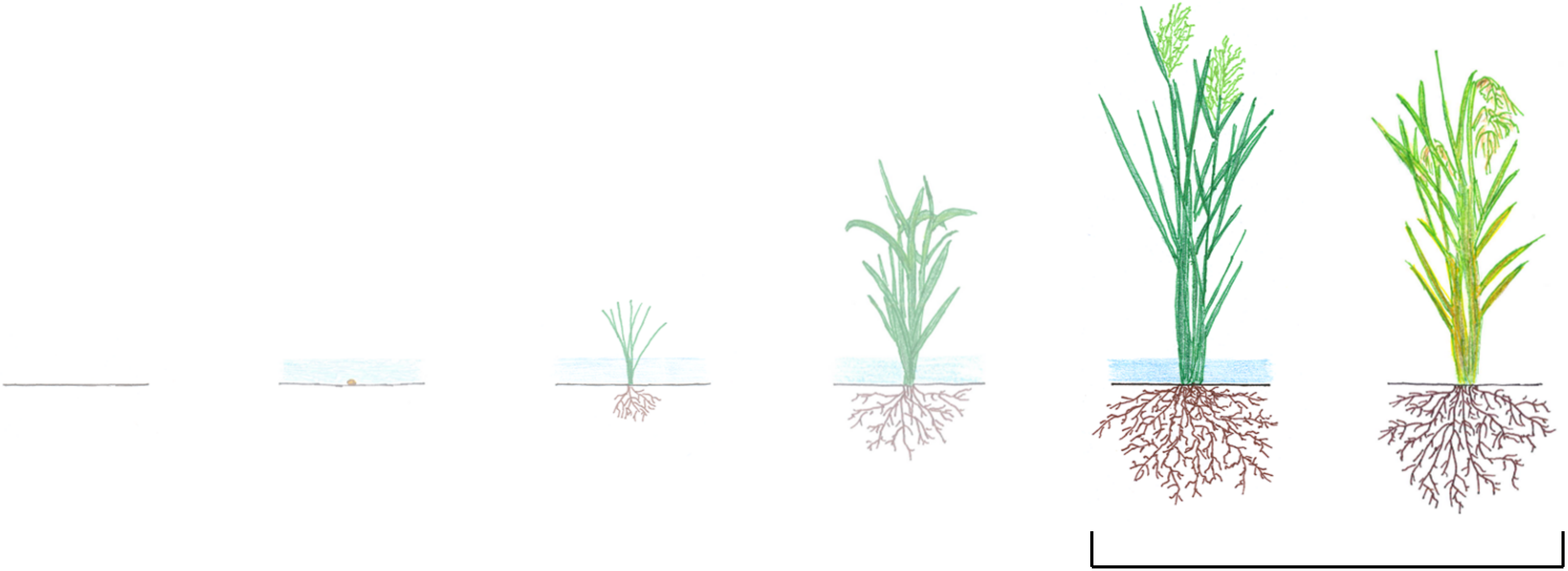
1) Plant

2) Leaf Emergence

3) Grain Fill

Phase 3: Grain Fill

Grain fill starts when **2-meter air temperature** reaches a crop-specific threshold (parameters listed in CLM5 Tech Note) or when the crop-specific **LAI threshold** is reached



Phenology

1) Plant

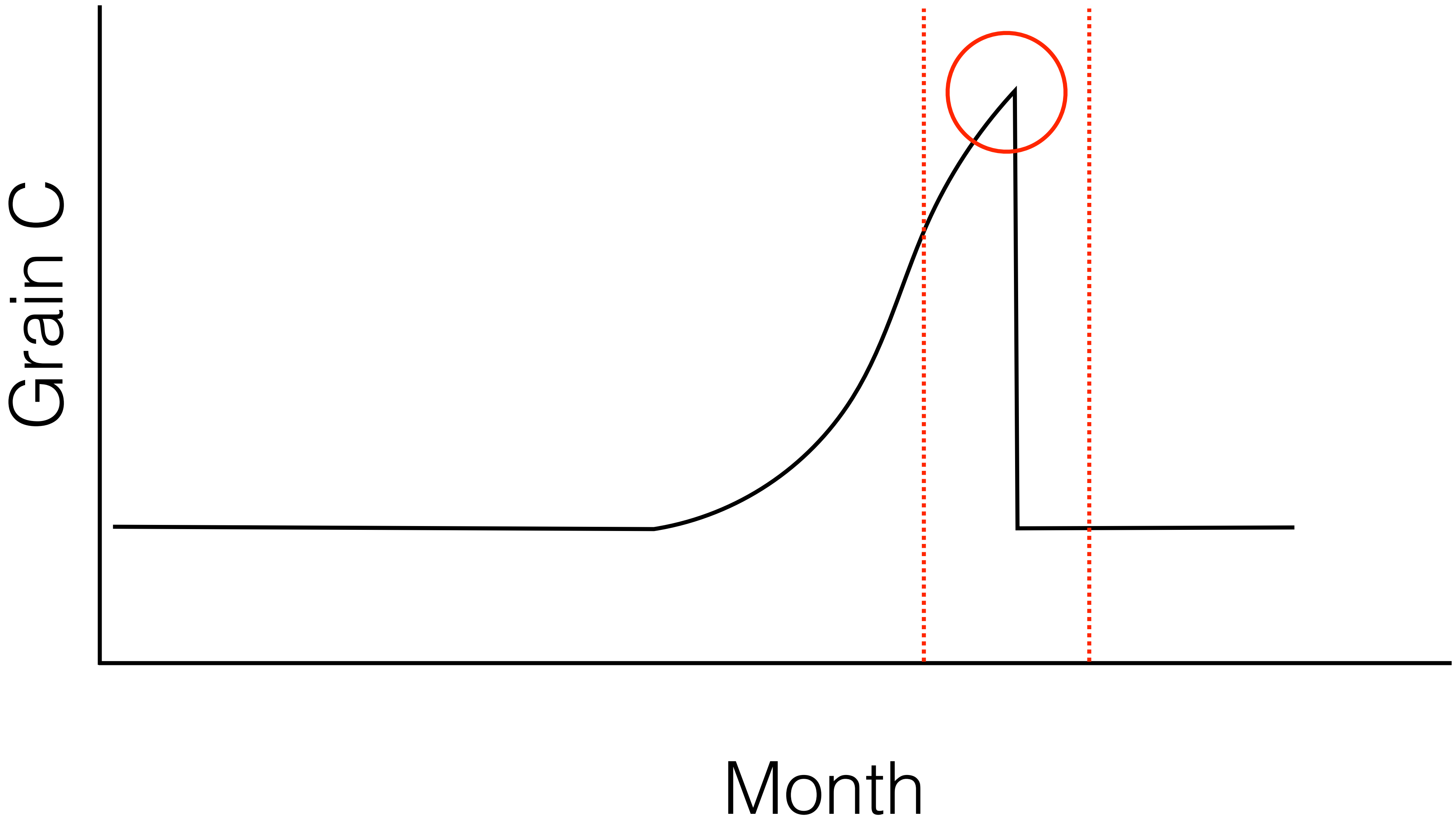
3) Grain Fill

2) Leaf Emergence

4) Harvest

Phase 4: Harvest

Harvest occurs when **2-meter air temperature** reaches a crop-specific threshold for maturity (parameters listed in CLM5 Tech Note) or at a maximum number of days past planting.



Harvest occurs in a single time-step using CLM's leaf offset algorithm. Therefore, the default monthly average Grain C history field will estimate grain yields. To calculate grain yields, we recommend summing the "GRAINC_TO_FOOD" variable

Phenology

1) Plant

2) Leaf Emergence

3) Grain Fill

4) Harvest


3) Allocation

Allocation

2) Leaf Emergence

3) Grain Fill

Allocation changes depending on which phenological phase the crop is in.
Allocation parameters also vary by crop type

Allocation

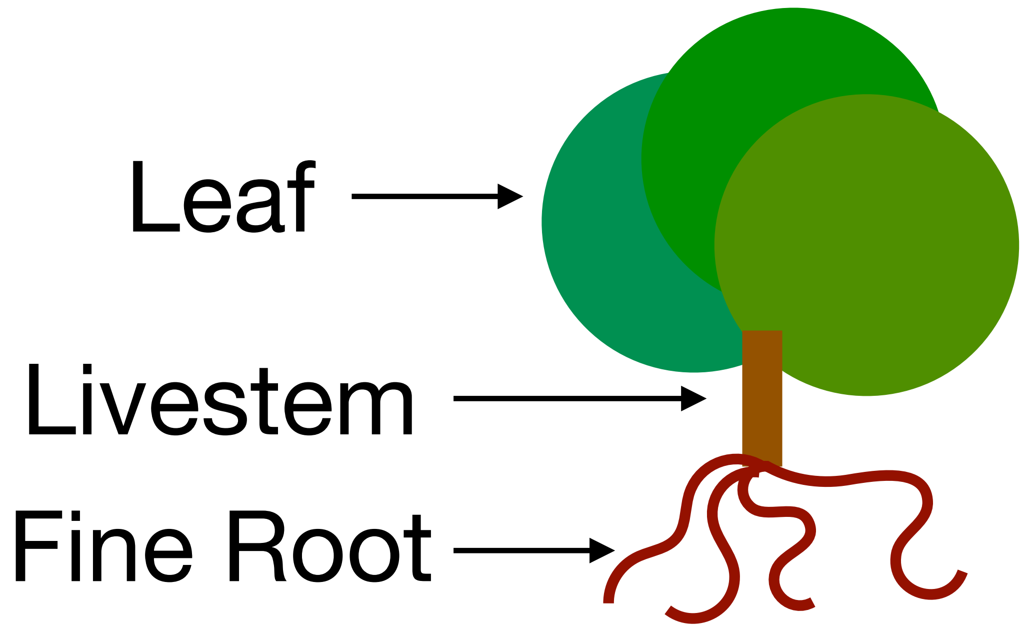
2) Leaf Emergence

3) Grain Fill

Allocation changes depending on which phenological phase the crop is in.
Allocation parameters also vary by crop type

During Leaf Emergence (Phenological Phase 2)

Carbon and nitrogen are allocated to the following pools:



Allocation to these pools are based on crop-specific parameters

Allocation

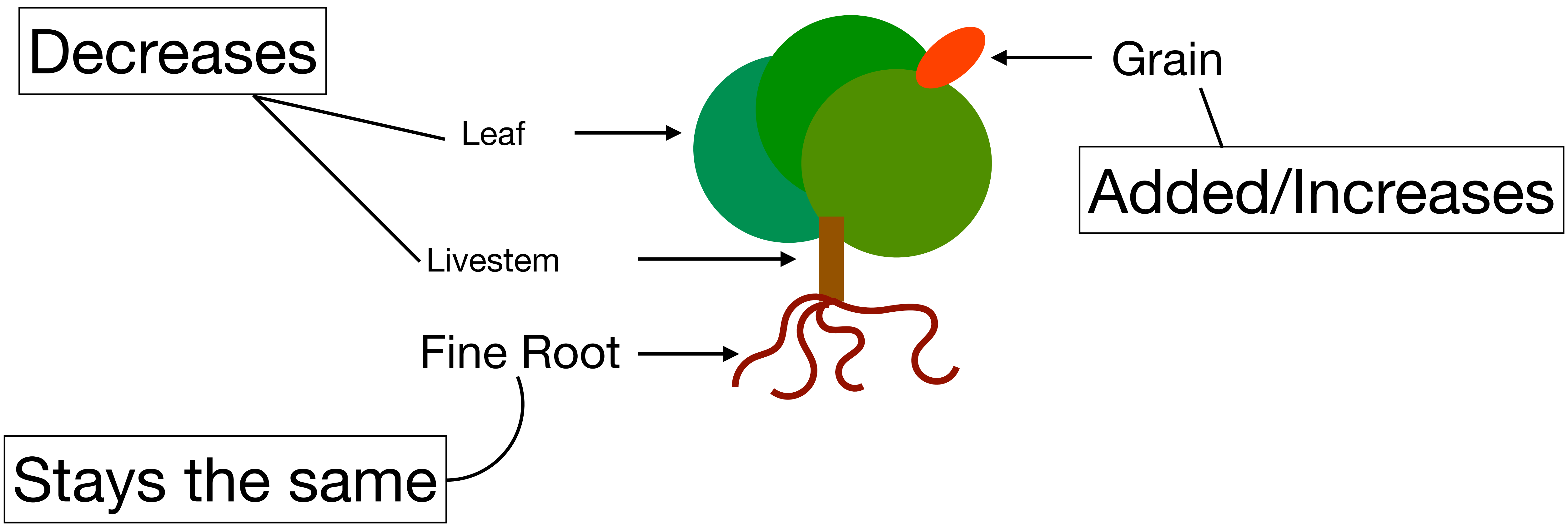
2) Leaf Emergence

3) Grain Fill

Allocation changes depending on which phenological phase the crop is in.
Allocation parameters also vary by crop type

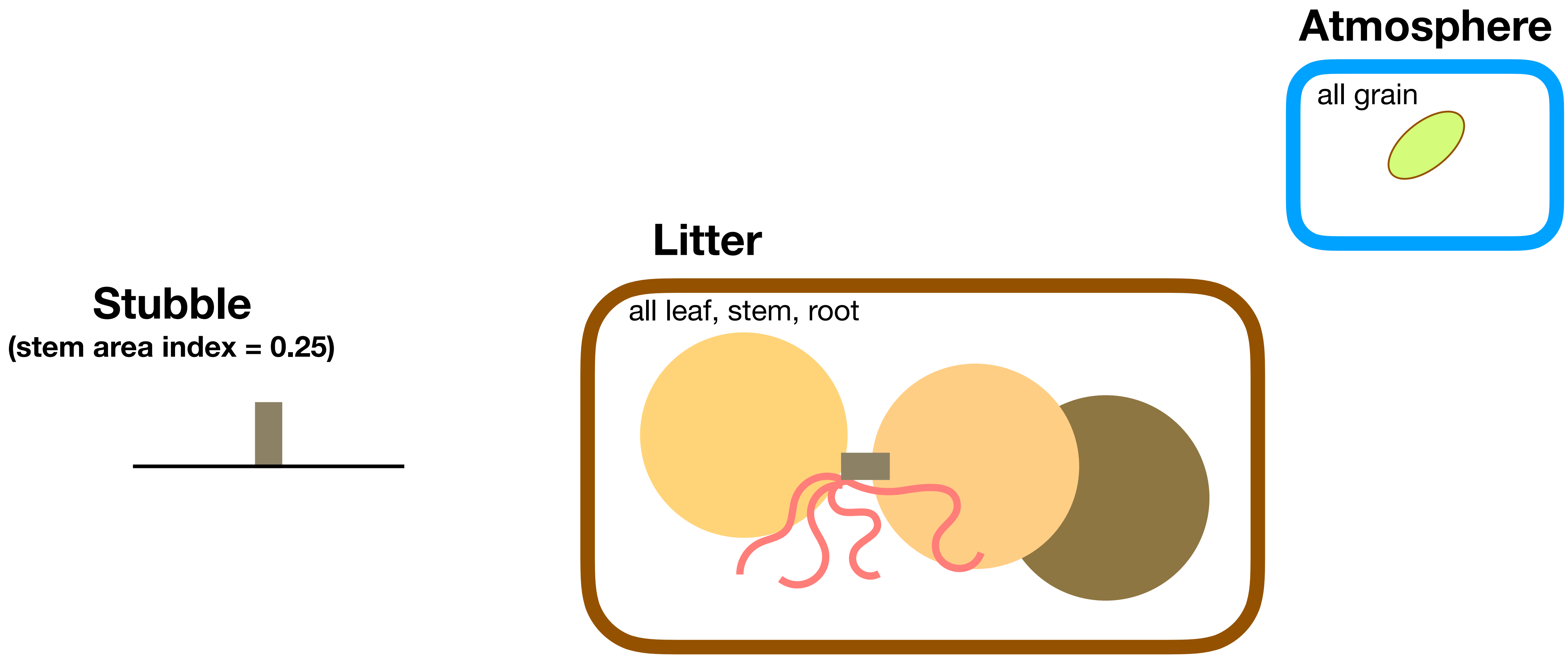
During Grain Fill (Phenological Phase 3)

C and N allocation changes:



Allocation to these pools are based on crop-specific parameters

At harvest



Atmosphere
all grain
Litter
all leaf, stem, root
Stubble
(stem area index = 0.25)

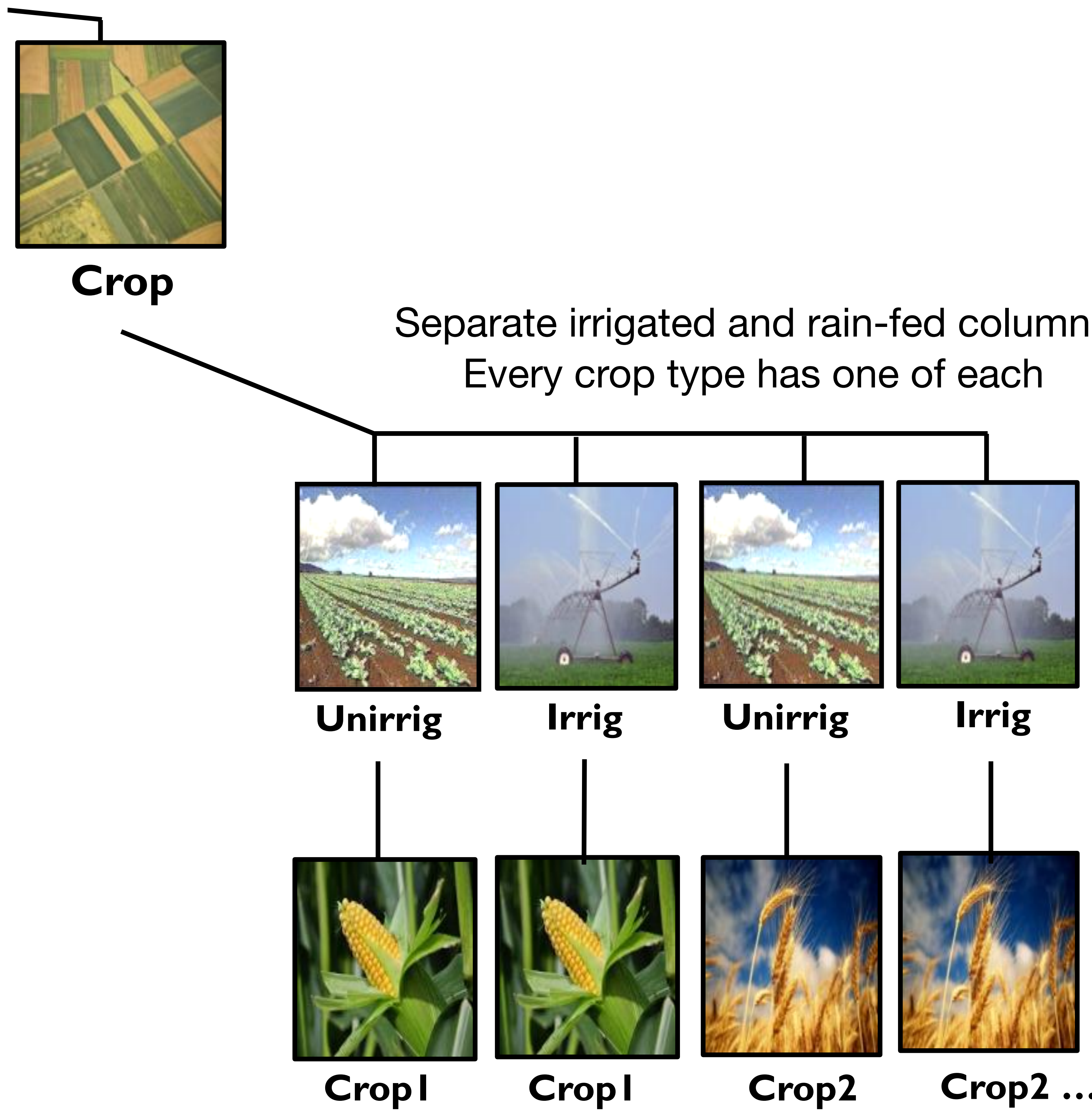
4) Management Options

Management

Fertilization

Irrigation

Crops exist on their own column so they don't compete for water or nitrogen

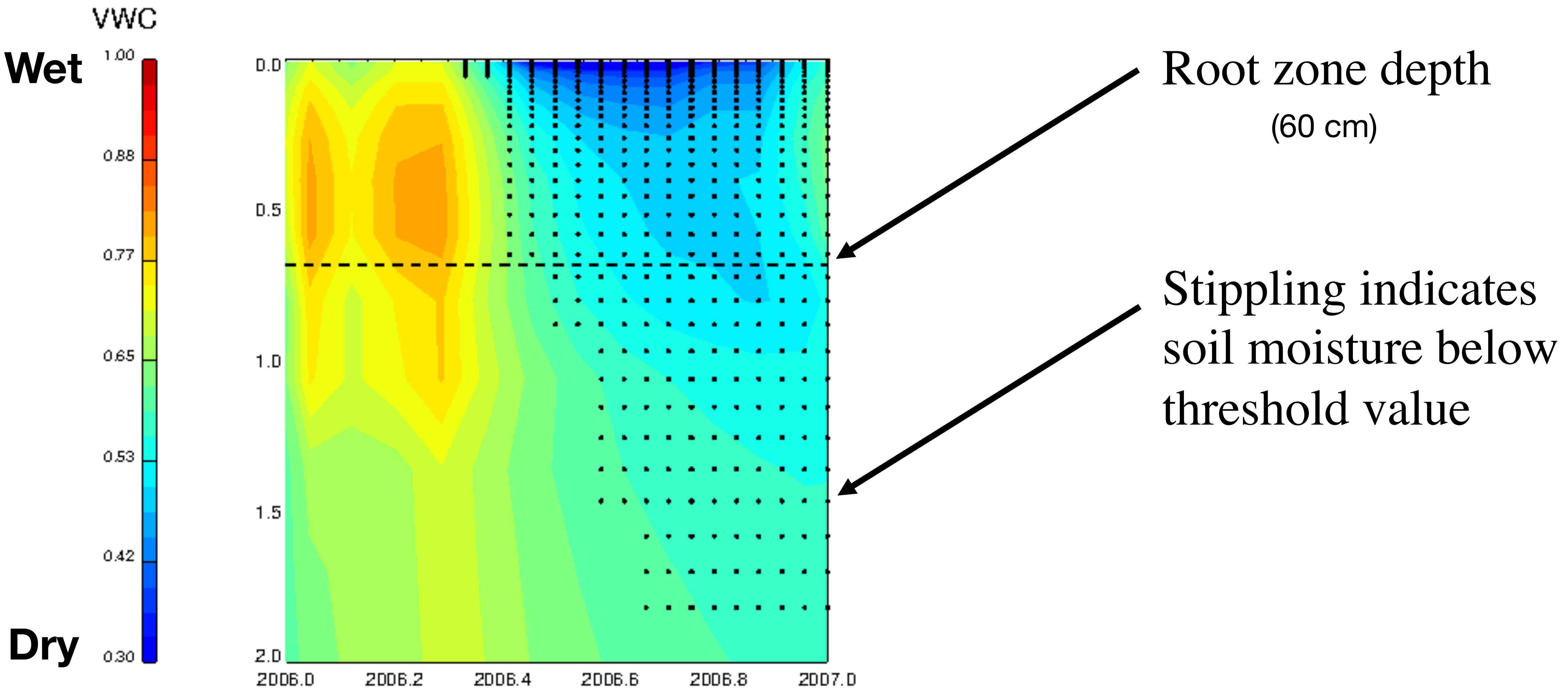


Irrigation

Irrigation is only applied to irrigated crop columns

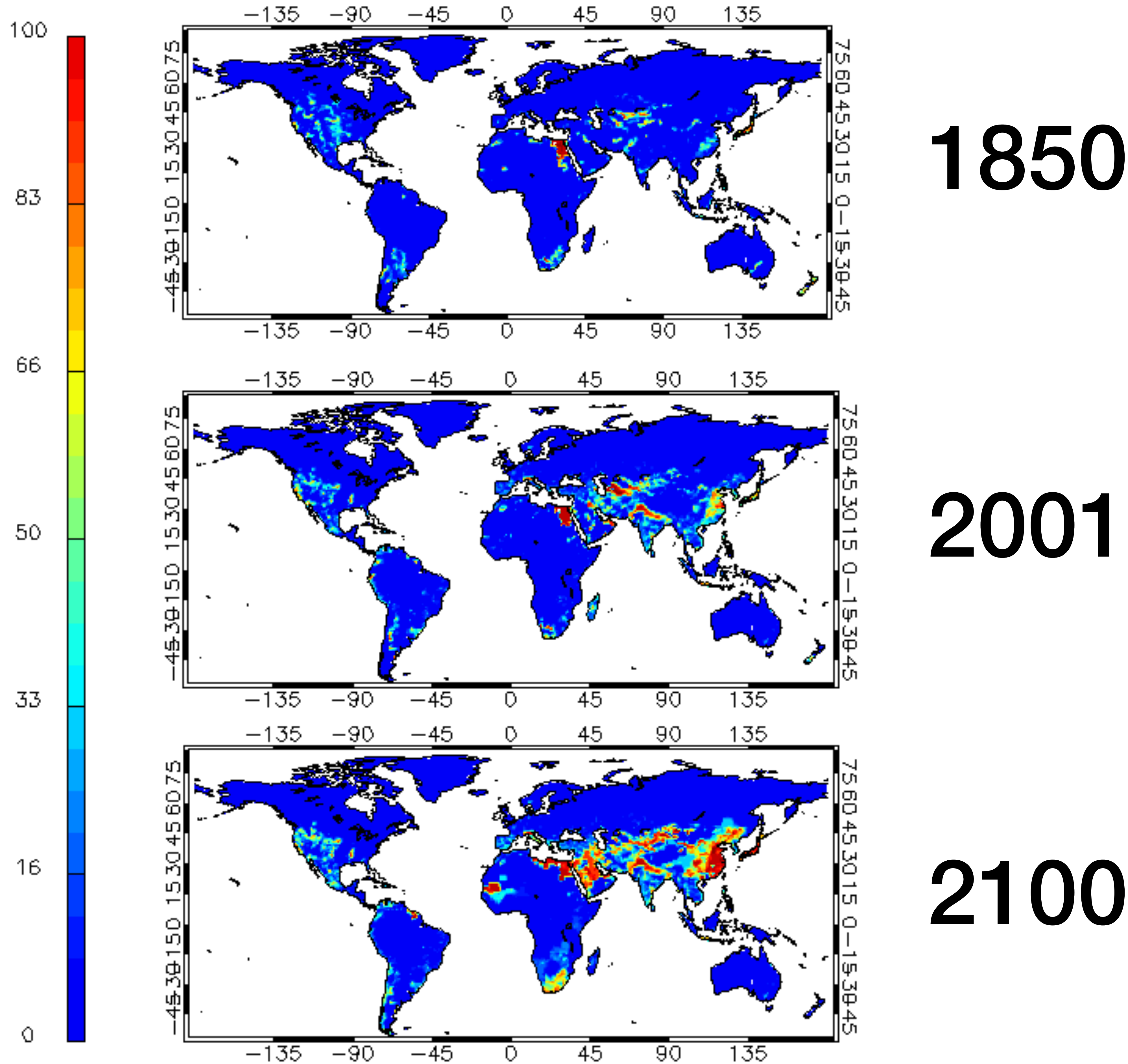
Irrigation is triggered by the soil moisture state in the root zone

The amount of irrigation depends on three parameters: root zone depth, target soil moisture, and difference between actual and target soil moisture



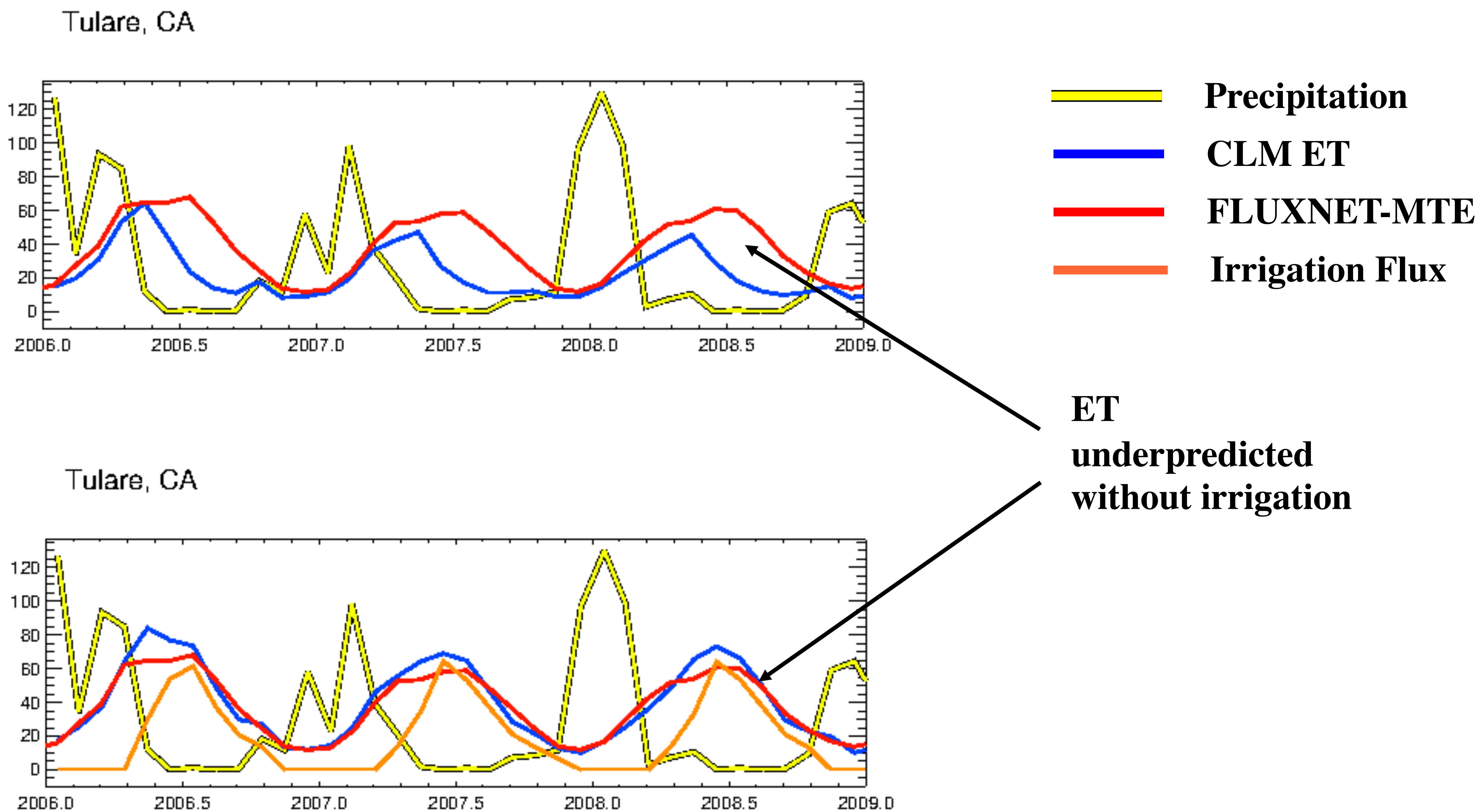
S. Swenson

Fraction of Crop Area That Is Irrigated



S. Swenson

Example: California's Central Valley



S. Swenson

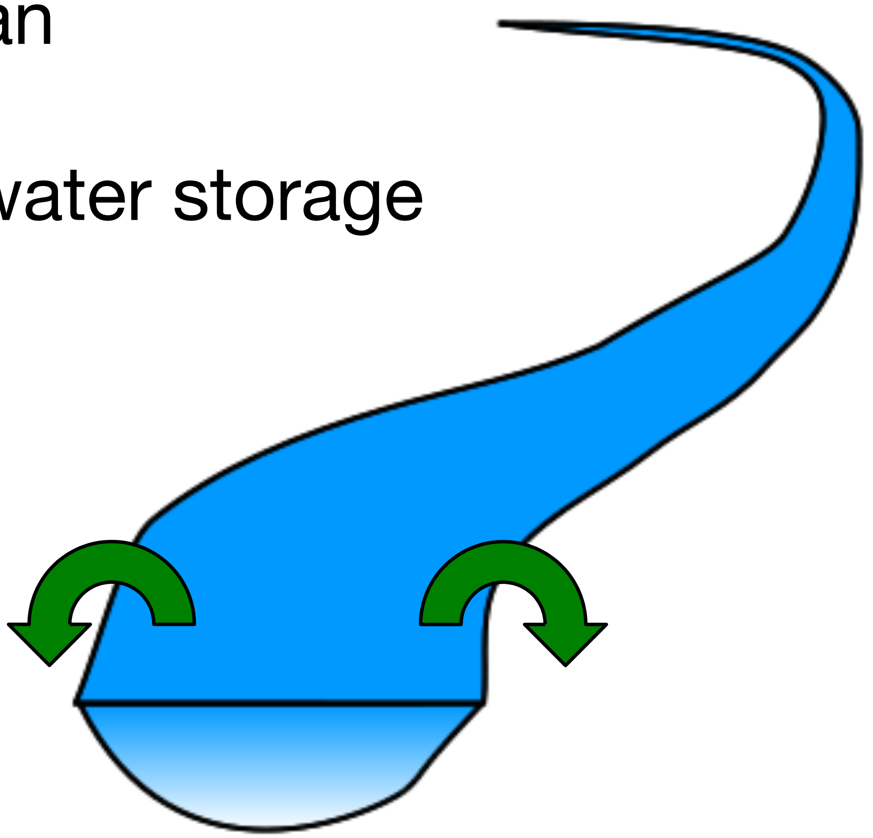
How is irrigation limited?

Irrigation demand is calculated independently of water availability, and irrigated water is removed from river water storage.

If river water is inadequate to meet irrigation demand:

1) additional water can be removed from the ocean

2) irrigation can be constrained to maintain river water storage above a threshold



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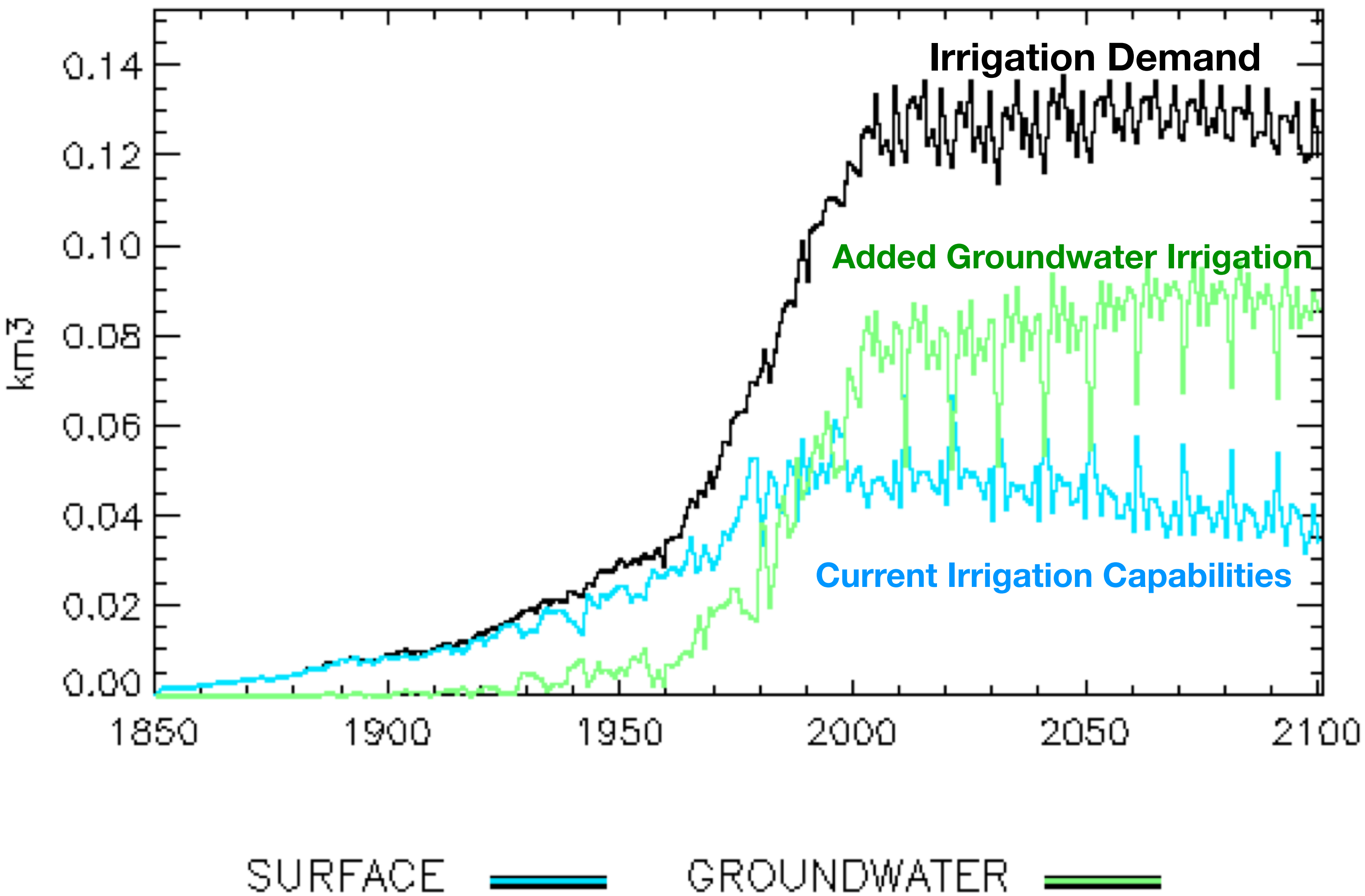
New Irrigation Capabilities

Annual irrigation
Northern India

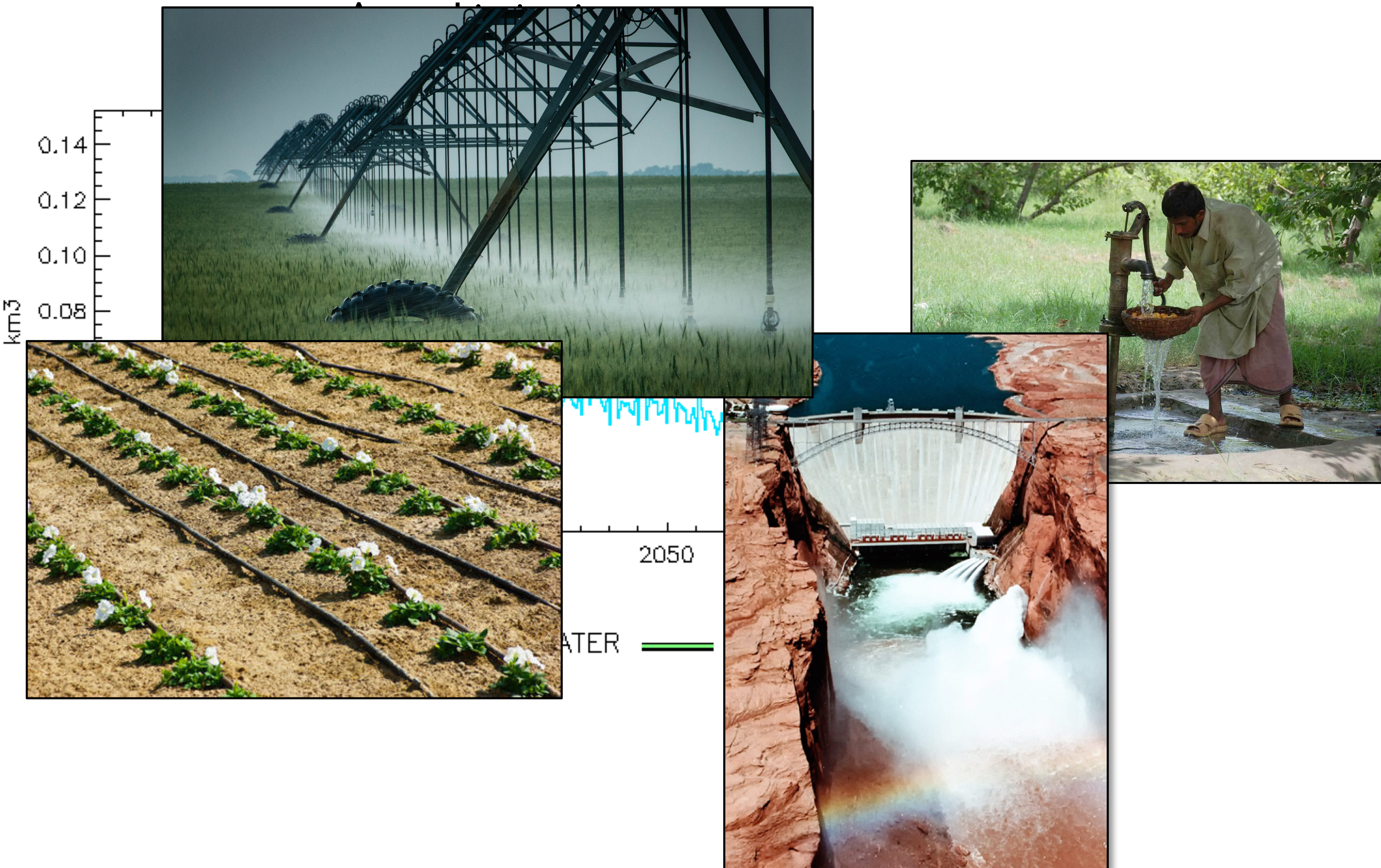


Introduce groundwater pumping

Assess relative withdrawals from surface water versus groundwater

Swenson/Lawrence

New Irrigation Capabilities



Swenson/Lawrence

Fertilizer

Fertilization begins during leaf emergence and runs for 20 days

Note that the slow application minimizes N loss and limits N application to emergence phase

Fertilizer is applied as two sources:

Manure (manunitro)

Applied at a rate of 0.002 kg N m-2 yr-1

Industrial (FERTNITRO_CFT)

Based on LUMIP land use and land cover change time series (LUH2 and SSPs)

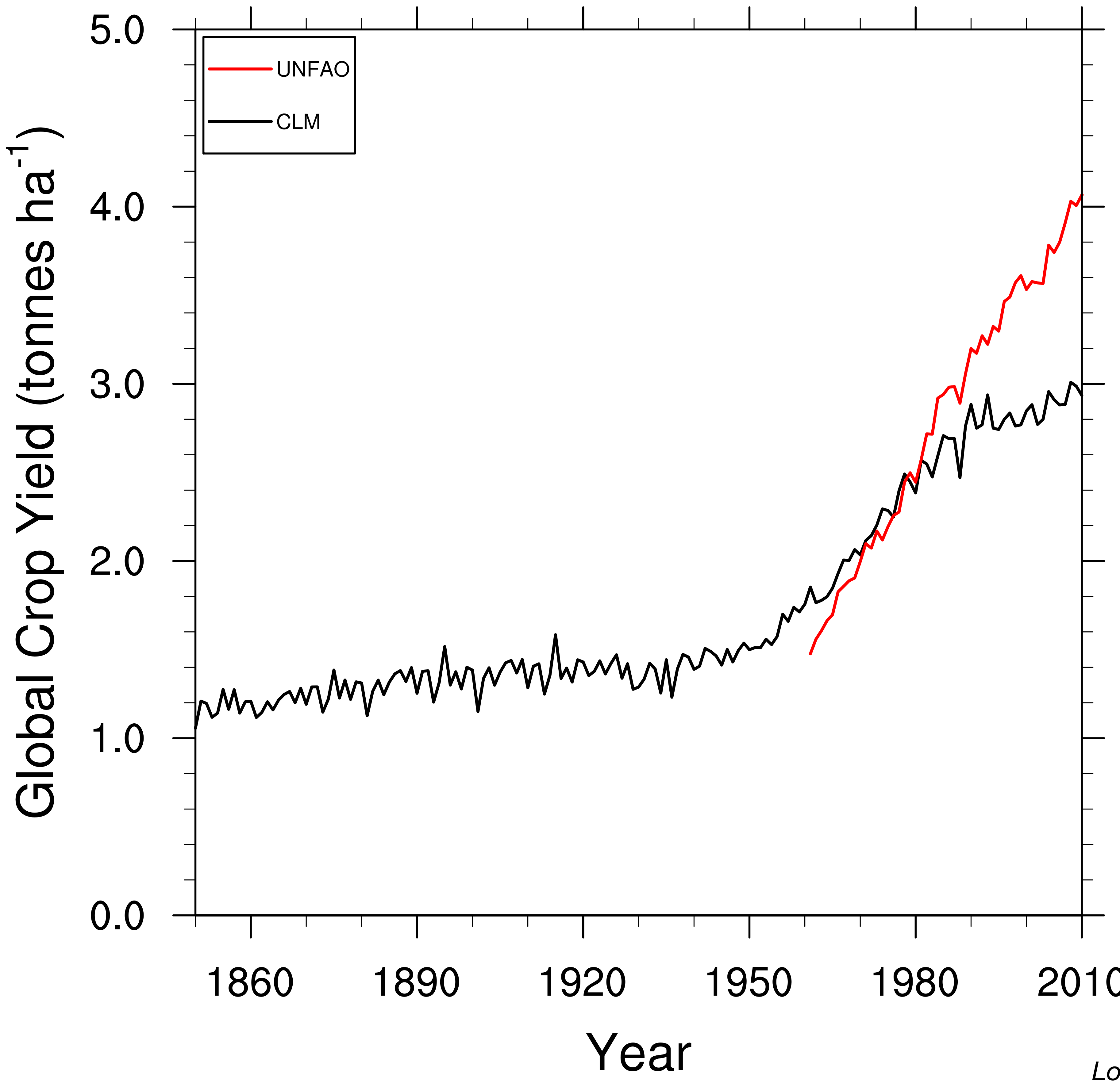
Prescribed by crop functional type

Varies spatially and temporally and specified on the land use time series

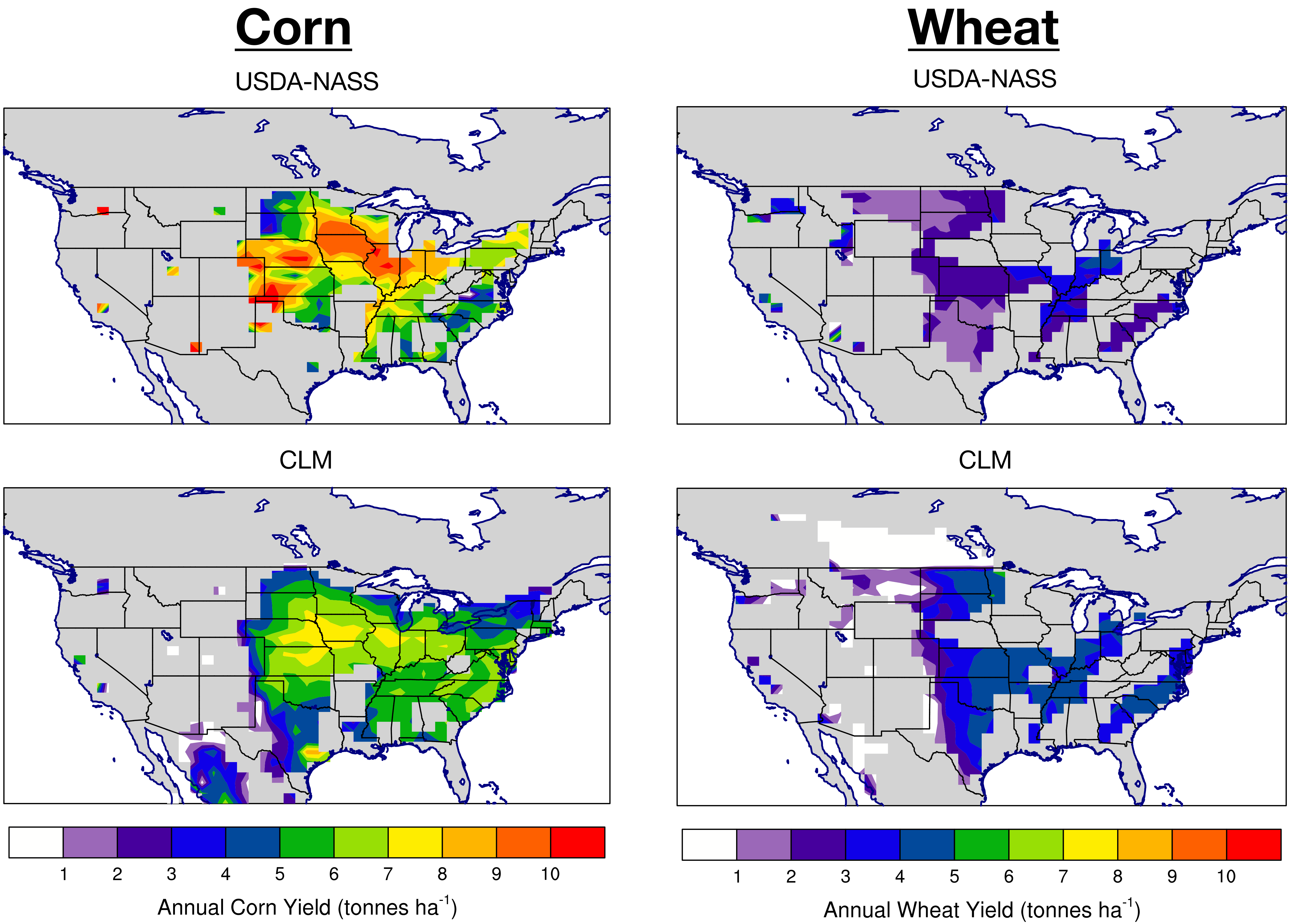
Note that for non-transient simulations, industrial fertilizer is constant and specified on the land surface dataset (CONST_FERTNITRO_CFT)

5) Crop Yields

Global Crop Yield

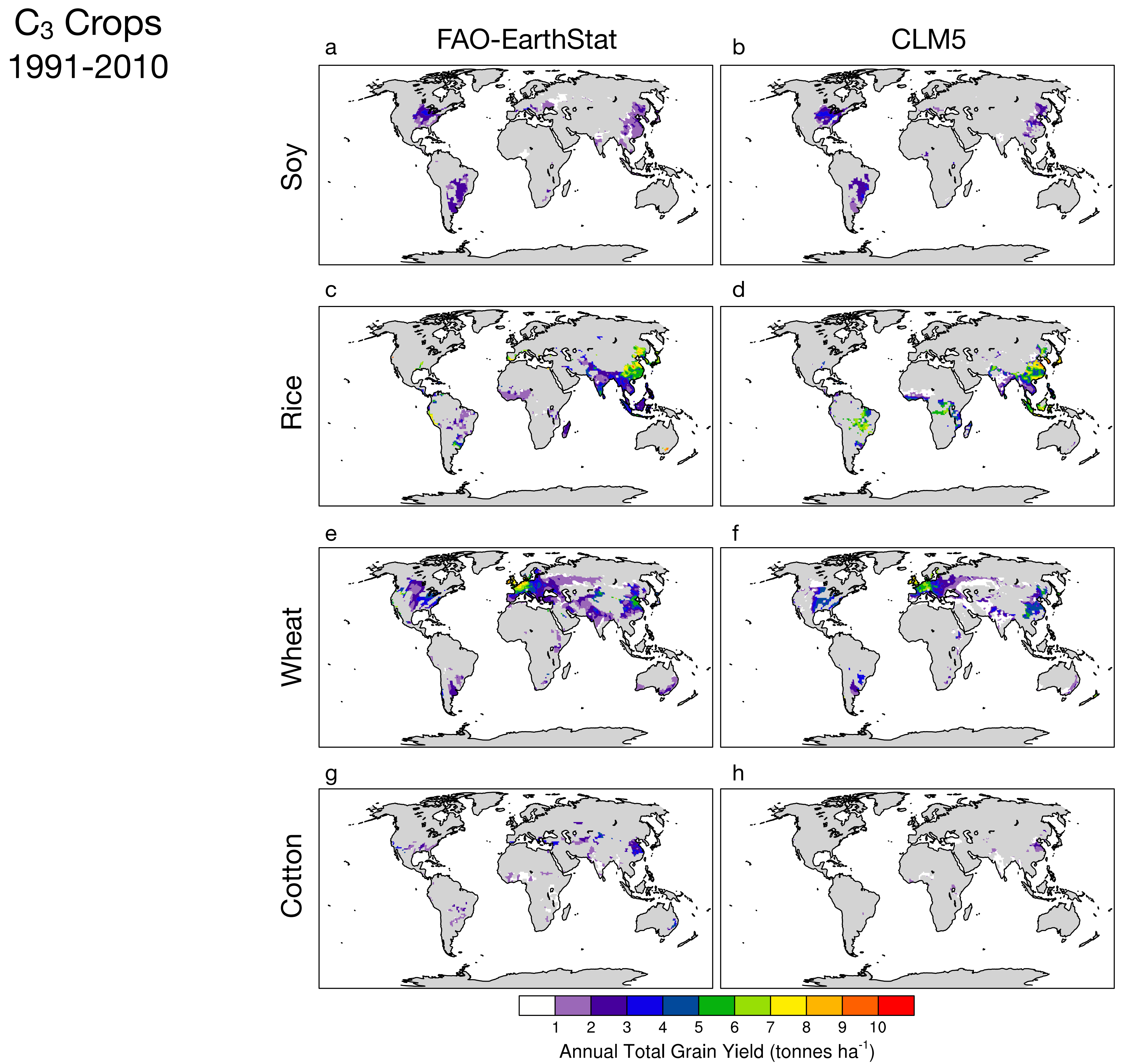


Lombardozzi et al. in review



Crop-type analysis: requires regridding from 1D to 3D, weighting by irrigated and rain-fed crop fractions, and weighting by % crop area and % crop type

Lombardozzi et al. in review



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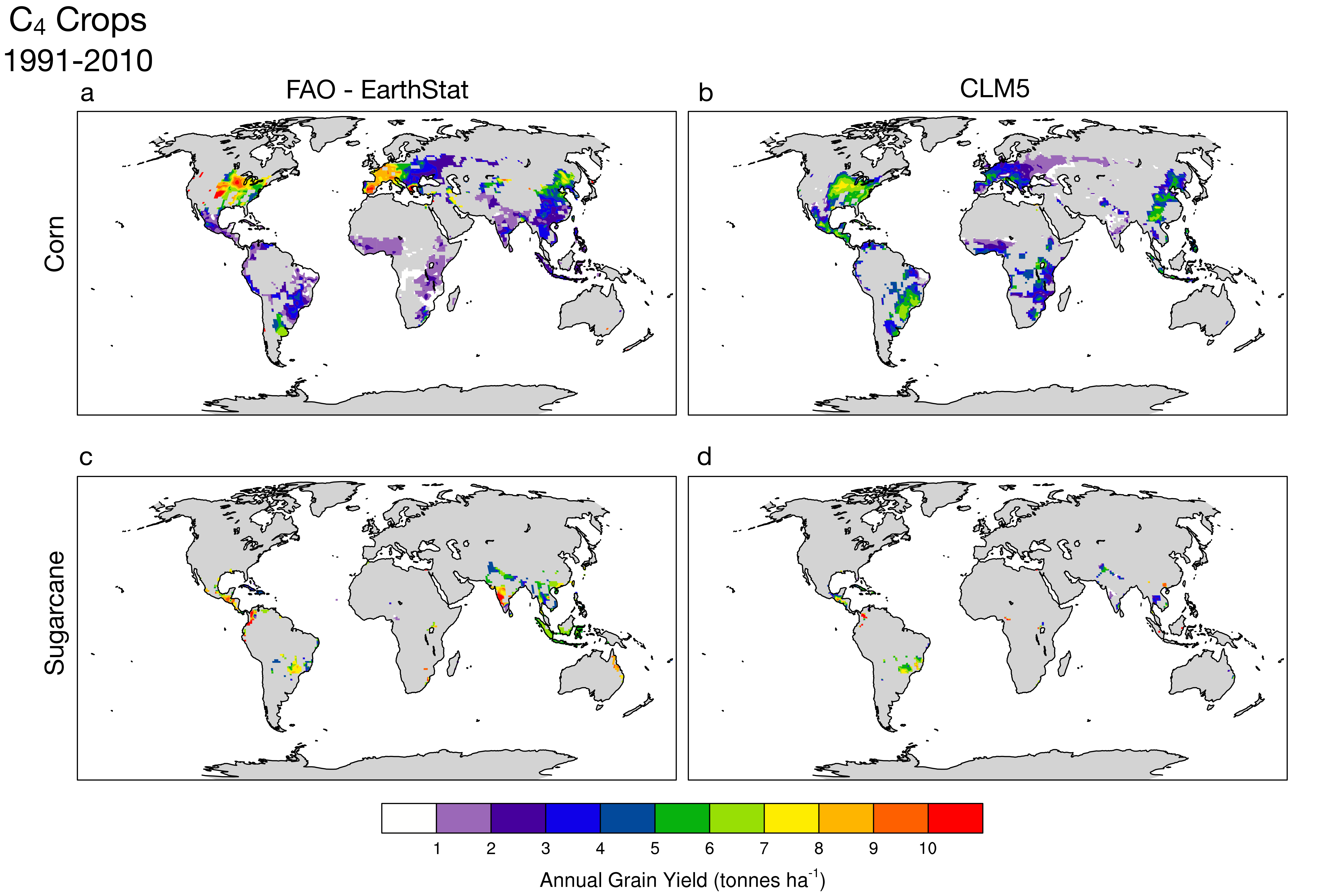

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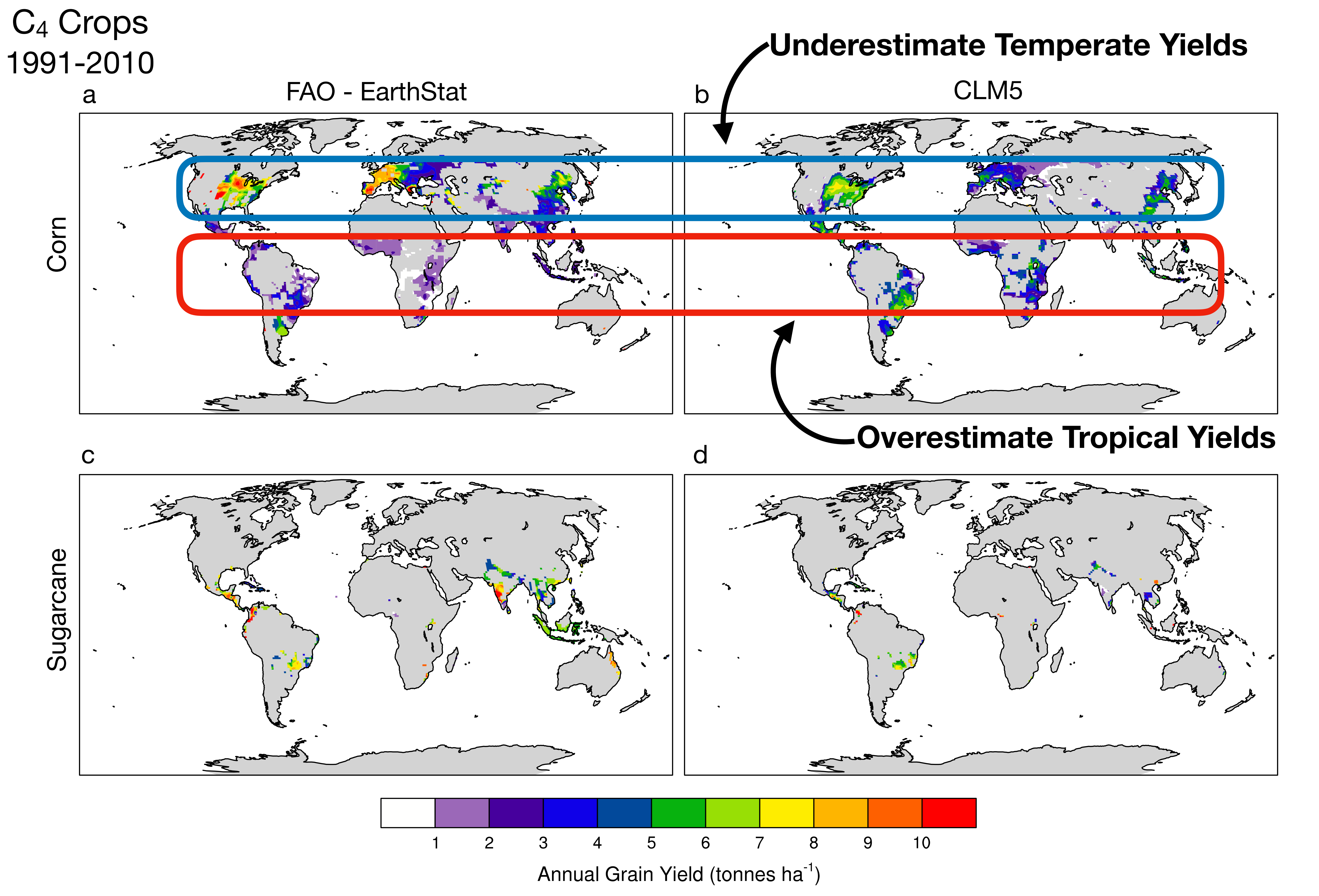

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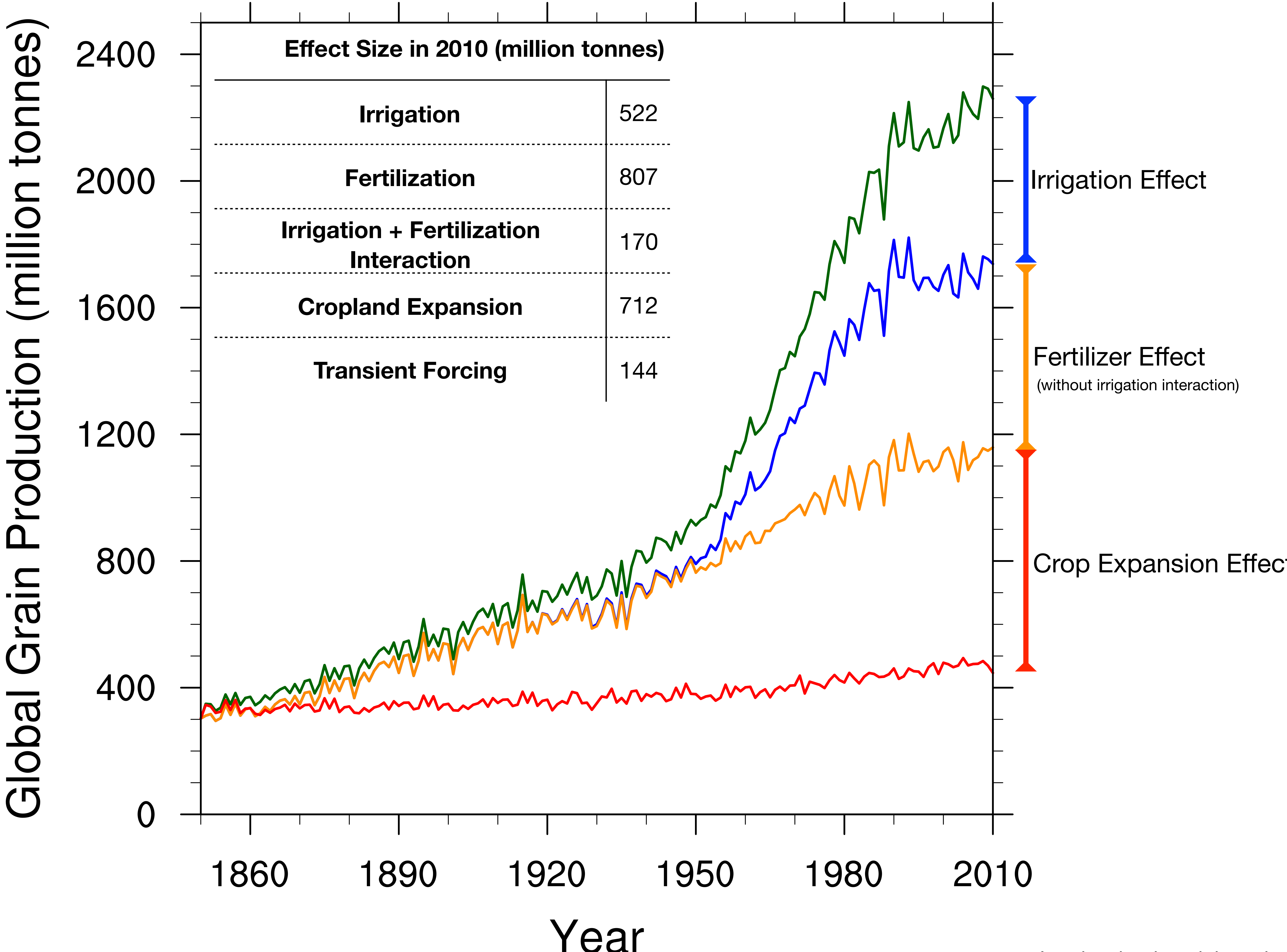


Lombardozzi et al. in review

6) Ongoing & Future Developments

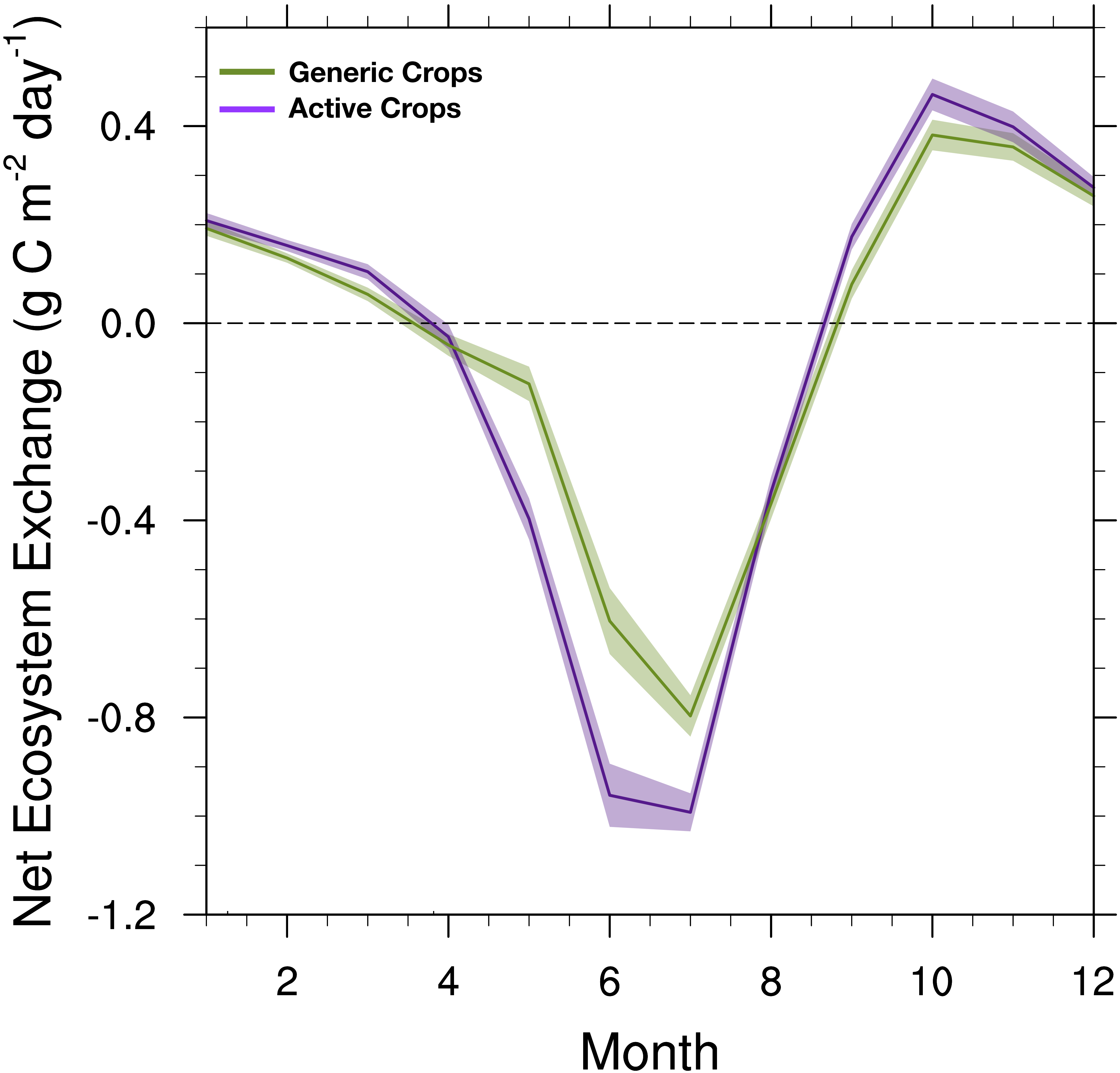
Ongoing or planned development activities

- Multiple irrigation application methods
- Soil tillage
- Cover crops
- Manure application, NH_3, & N_2O emissions
- APSIM crop model with additional phenological stages, including heat stress
- Spatially explicit planting windows
- Shifting cultivation
- Additional crop types (switchgrass, oil palm, winter wheat)
- Managed pasture
- Managed trees/timber

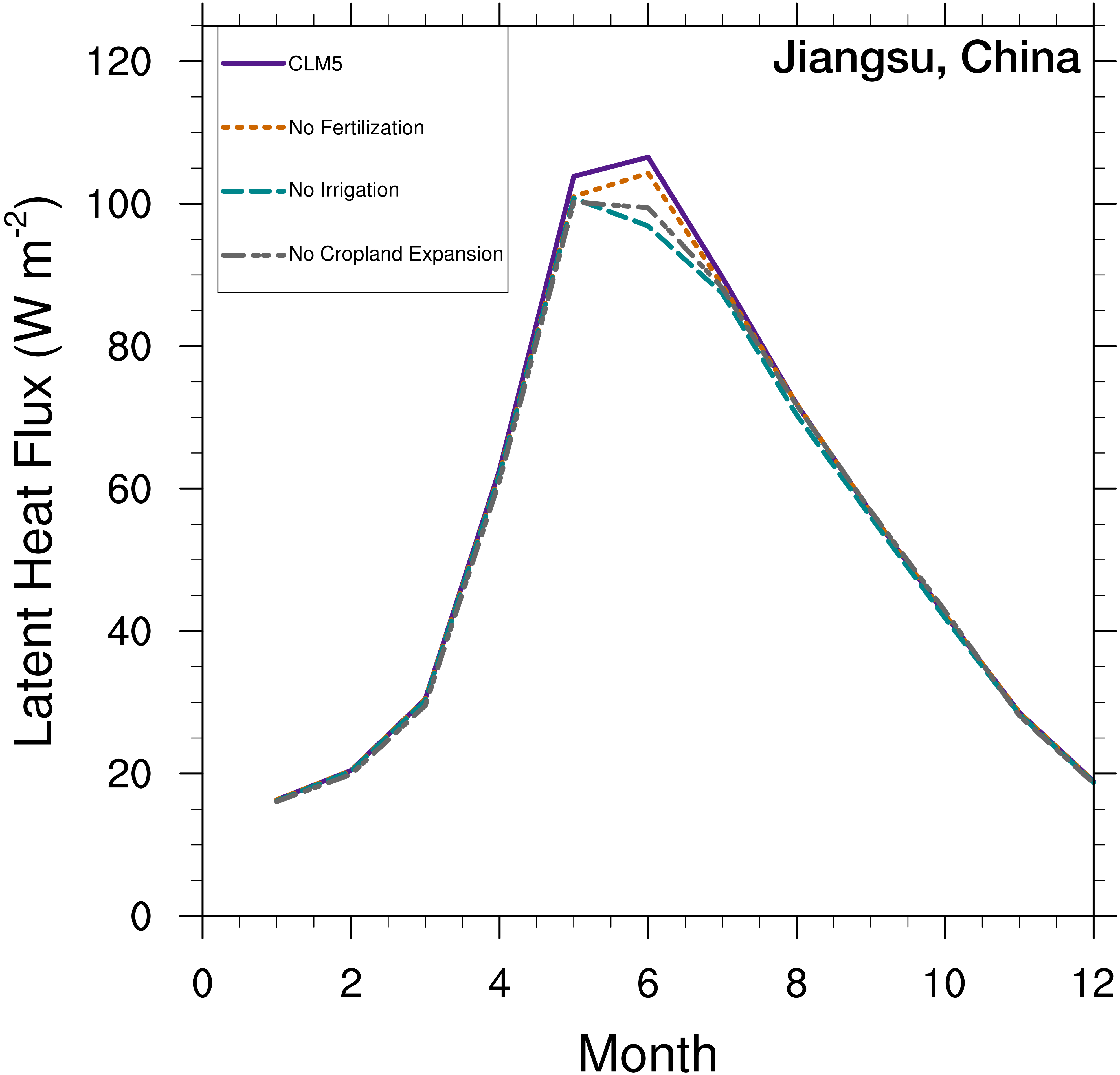
New: CTSM Agriculture Working Group

To facilitate development and application of CTSM-Crop

Interested in joining? Contact me (dll@ucar.edu)



Lombardozzi et al. in review



Lombardozzi et al. in review