RCE North Texas

RCE North Texas Annual Summit 2022

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Agricultural Sustainability: Challenges and Opportunities

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The Global Food and Water Paradox

- Feeding more people with less water than we have now, in a **changing climate**
- Roughly one-third of food produced is wasted globally (1.3 Bil Ton/yr)
- 70% of global water withdrawals

Urbanization

Deforestation

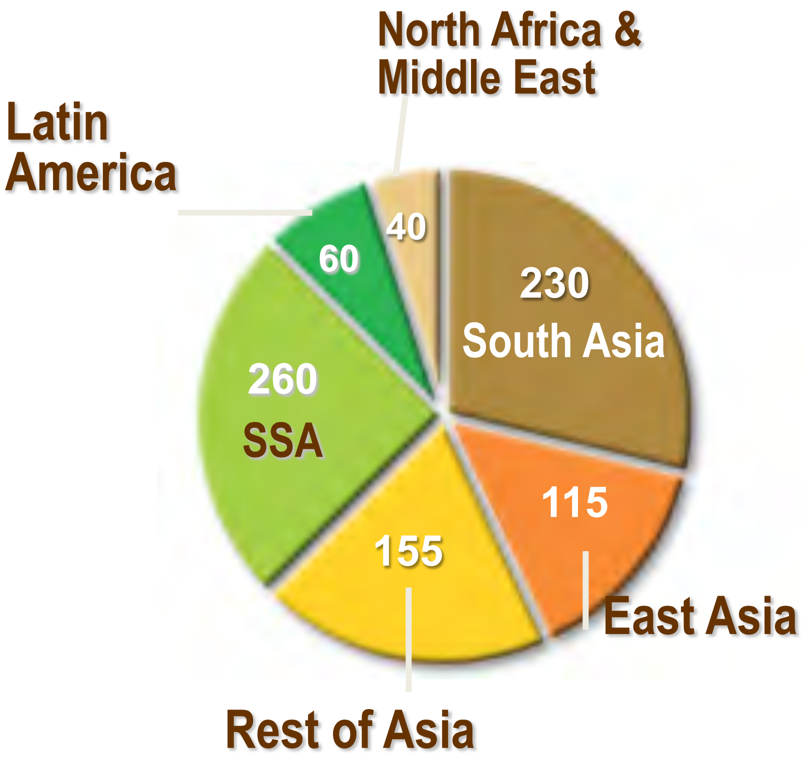
Fires/Land Degradation

Soil Erosion

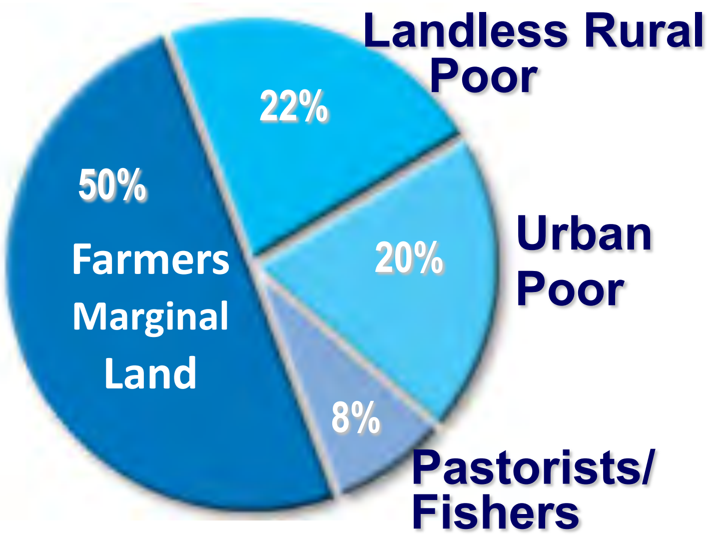
Water quality

800 Million Hungry People

Where are they?



Who are they?

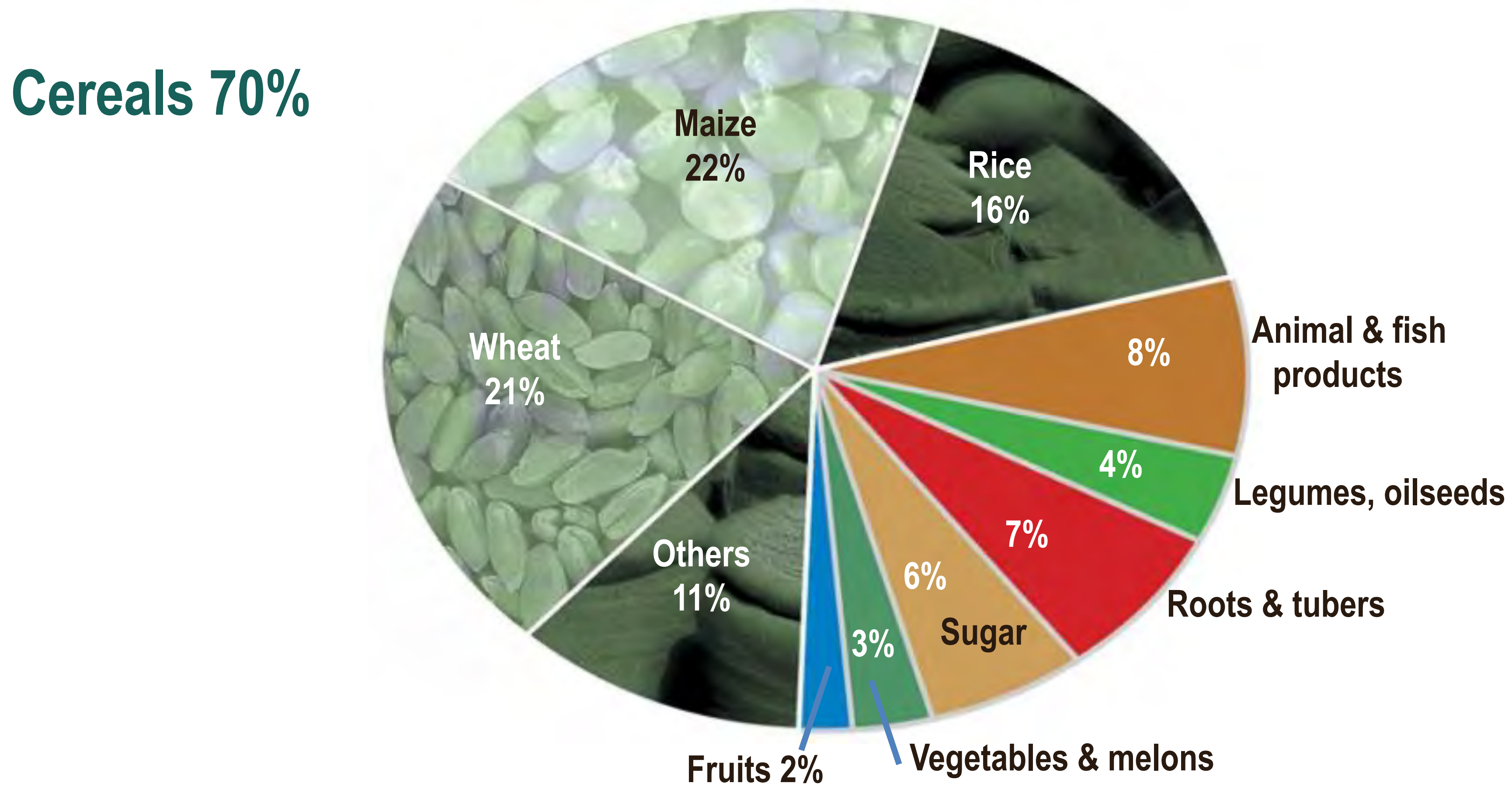


FAO, 2018

World Food Supply

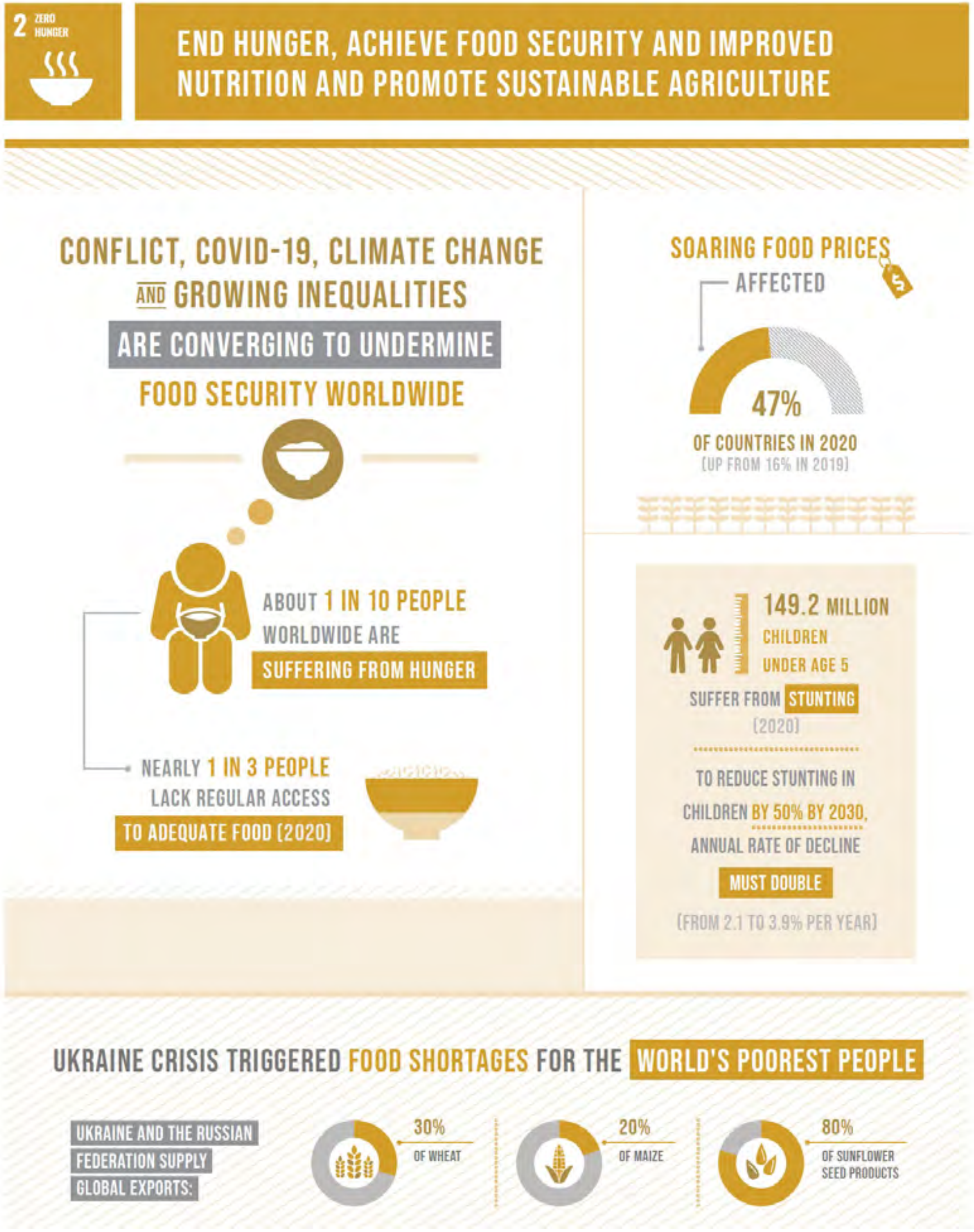
5.2 billion gross tonnes; 2.5 billion tonnes dry weight

Edible dry matter, expressed in Kcals

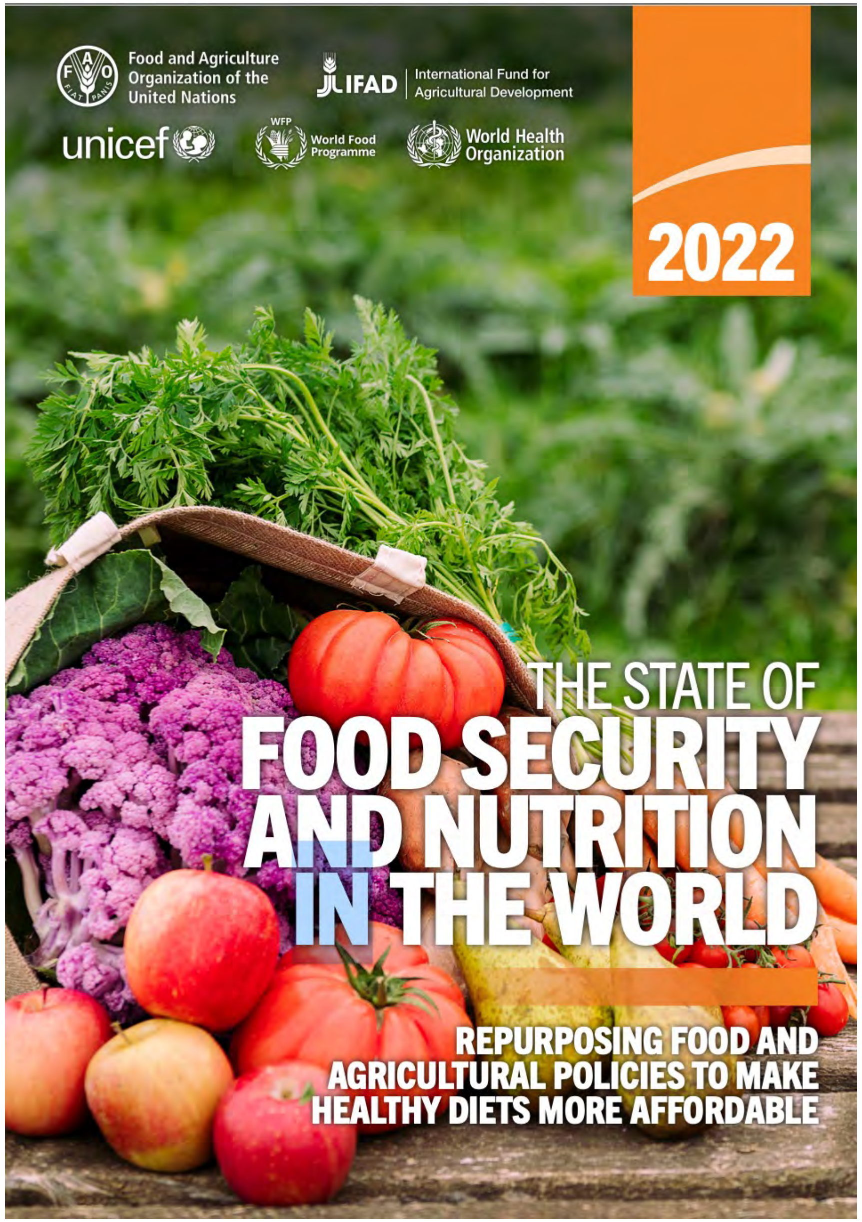


Source: FAO AGROSTAT, 2021

Nexus examples and direct relationships to SDGs



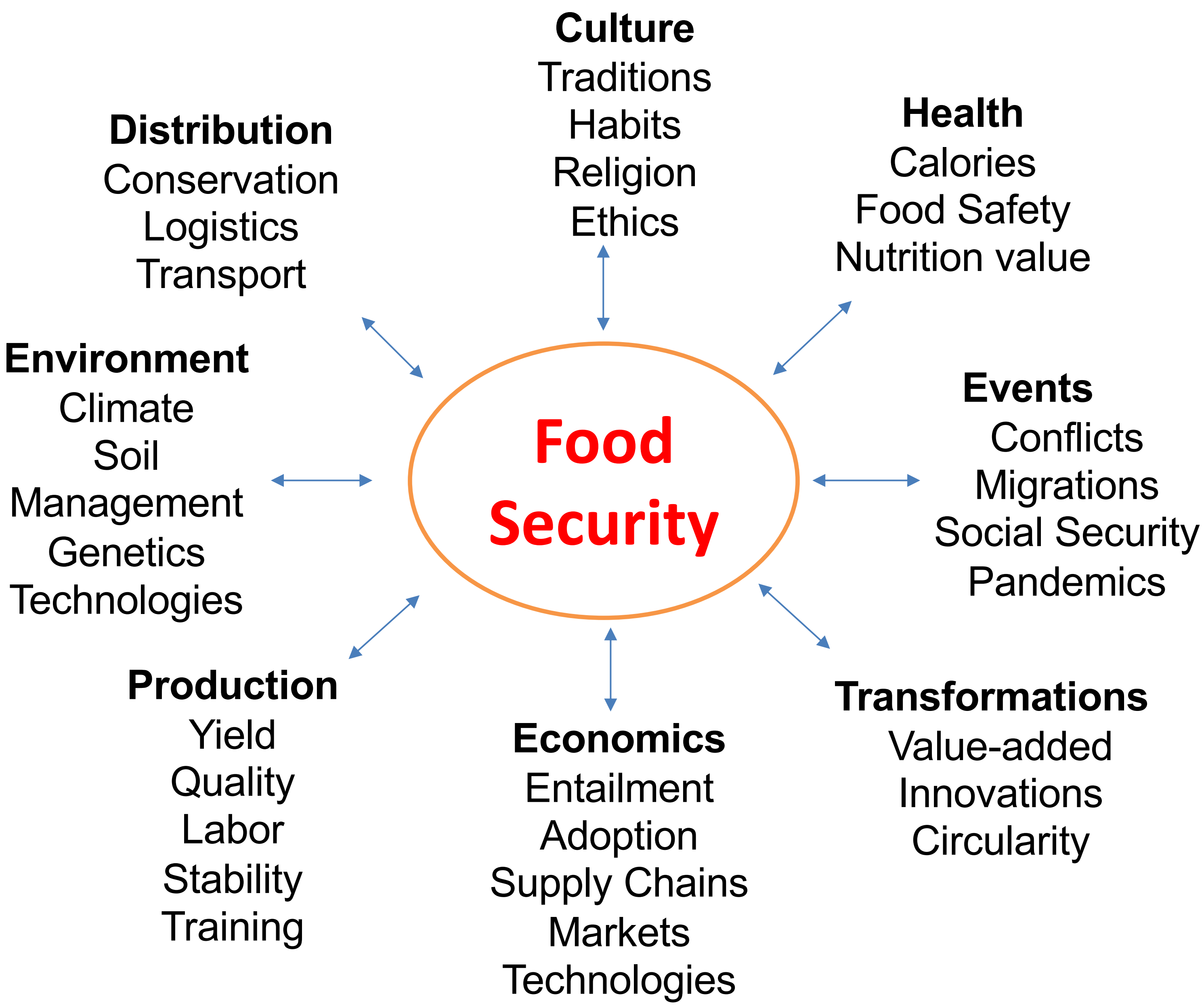
Food Security



Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life.

Source: FAO

The Complexity of Food Security System



“When reality is changing faster than theory suggests it should, a certain amount of nervousness is a reasonable response” The Economist

Sustainability

Sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs. Therefore, stewardship of both natural and human resources is of prime importance.

A systems perspective is essential to understanding sustainability. The system is envisioned in its broadest sense, from the individual farm, to the local ecosystem, and to communities affected by this farming system both locally and globally.

An emphasis on the system allows a larger and more thorough view of the consequences of farming practices on both human communities and the environment.

A systems approach gives us the tools to explore the interconnections between farming and other aspects of our environment. A systems approach also implies interdisciplinary efforts in research and education. This requires not only the input of researchers from various disciplines, but also farmers, farmworkers, consumers, policymakers, and others.

Sustainable agriculture

The basic goals of sustainable agriculture are environmental health, economic profitability, and social and economic equity.

Sustainable agriculture is commonly defined as integrated system of plant and animal production practices having a site-specific application that will over the long term:

- Satisfy food, fiber, feed, fuel needs
- Enhance environmental quality
- Increase resource use efficiency
- Sustain the economic viability of farm operations
- Enhance the quality of life for farmers and society as a whole

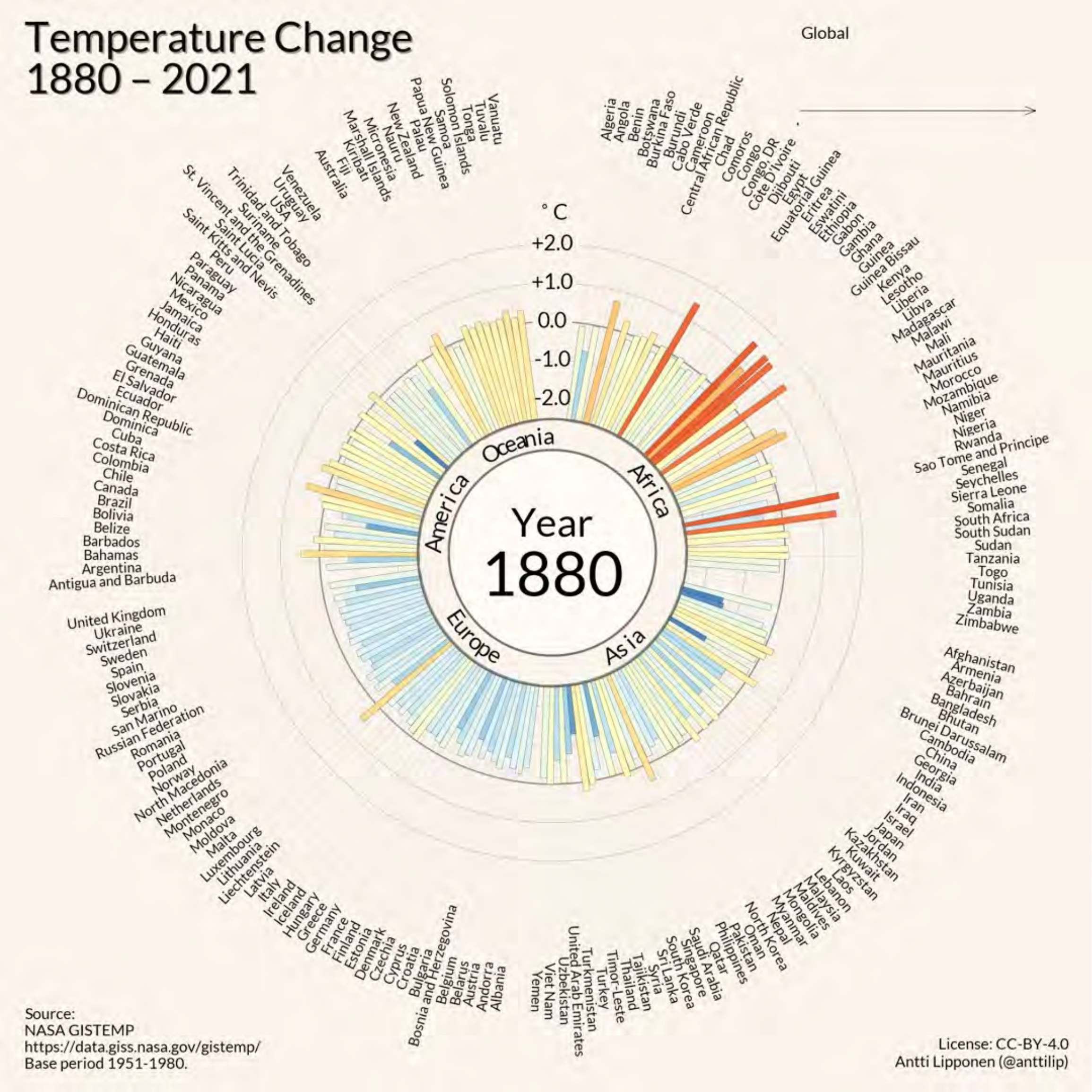
Reducing GHGs emission for climate mitigation

Curbing GHGs emissions is necessary to avoid warming of the earth of 1.5 or 2.0 C

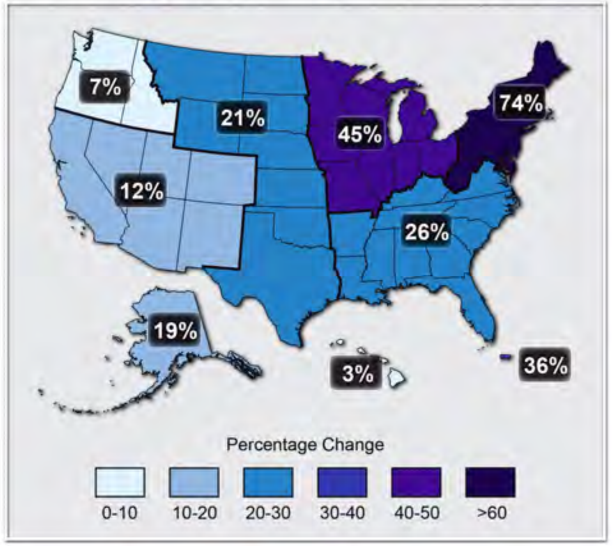
Agriculture, food systems, forestry play a critical role at creating avoided and negative emissions (Northup et al 2021; Clark et al., 2020; Rogelj et al., 2018; Field et al., 2020)

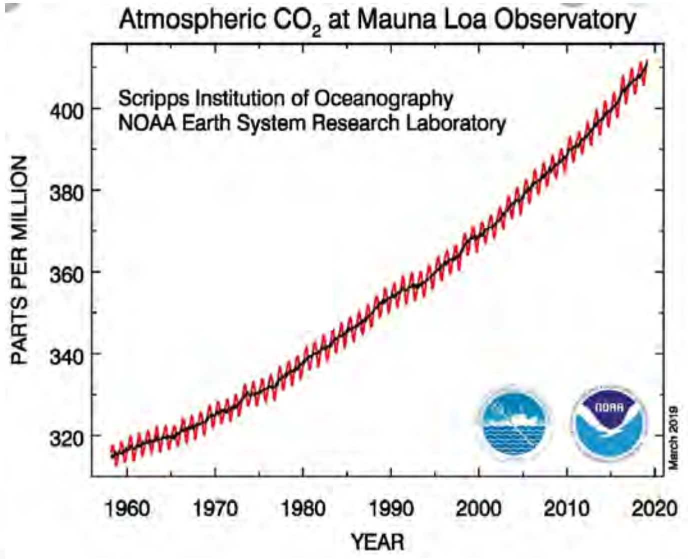
Land-based solutions provide important opportunity in offsetting fossil fuel use and provide immediate benefits (Robertson et al., 2022)

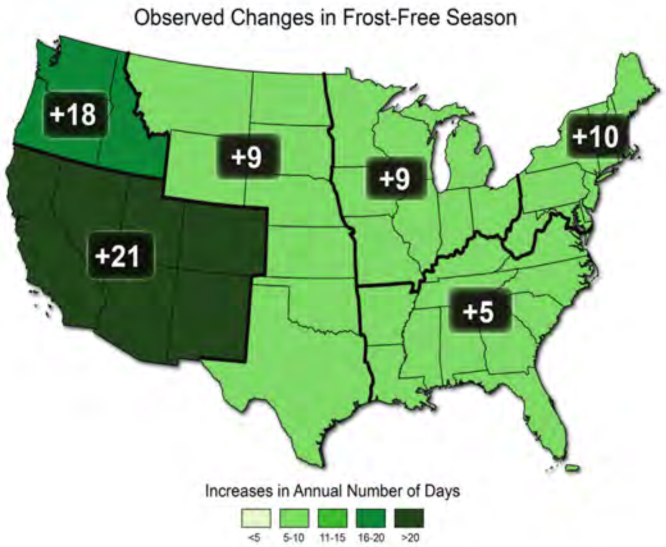
Climate Variability and Change



Precipitation





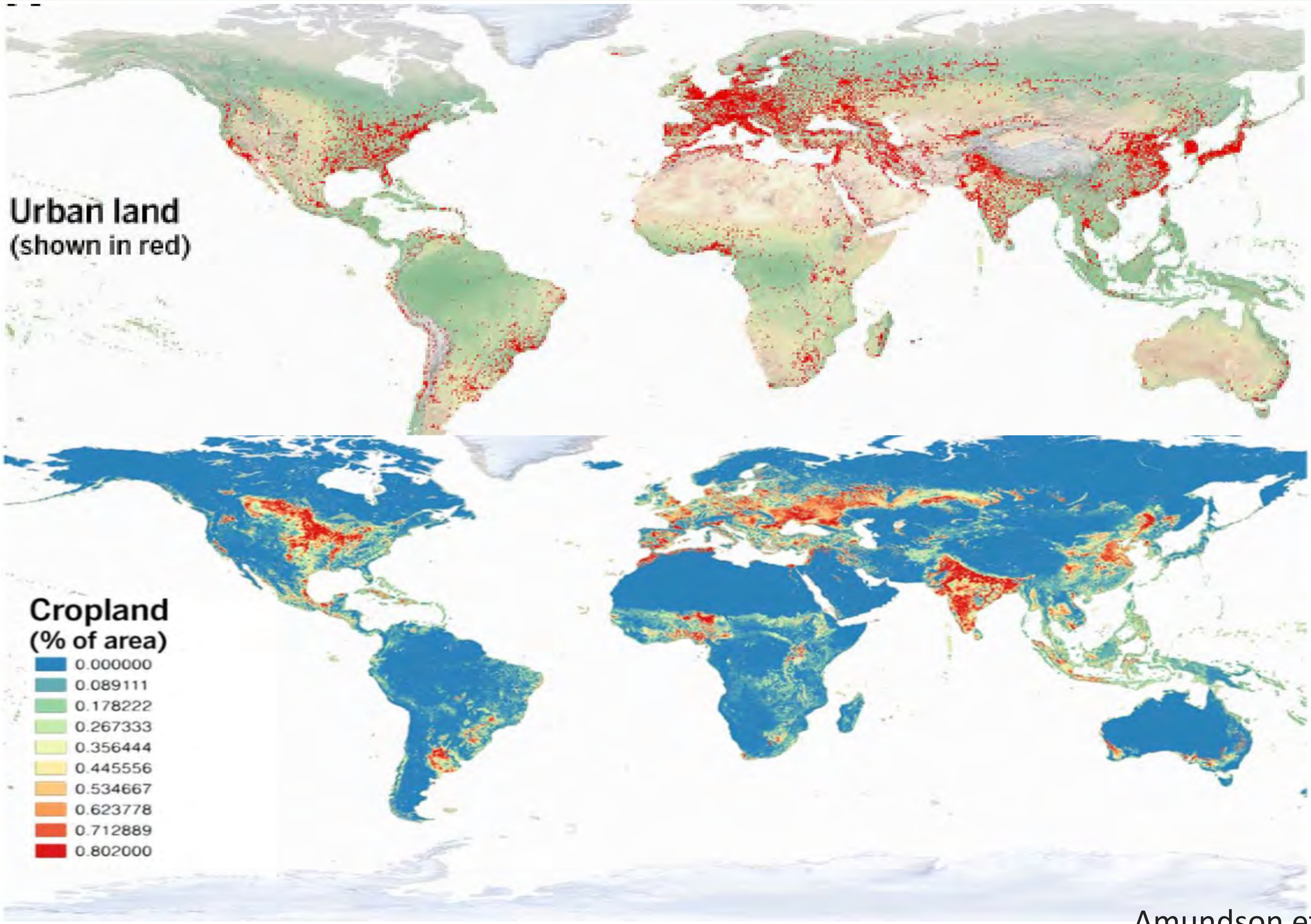


arbon dioxide now
more than 50% higher
than pre-industrial

urrent CO2 concentration
.6 ppm

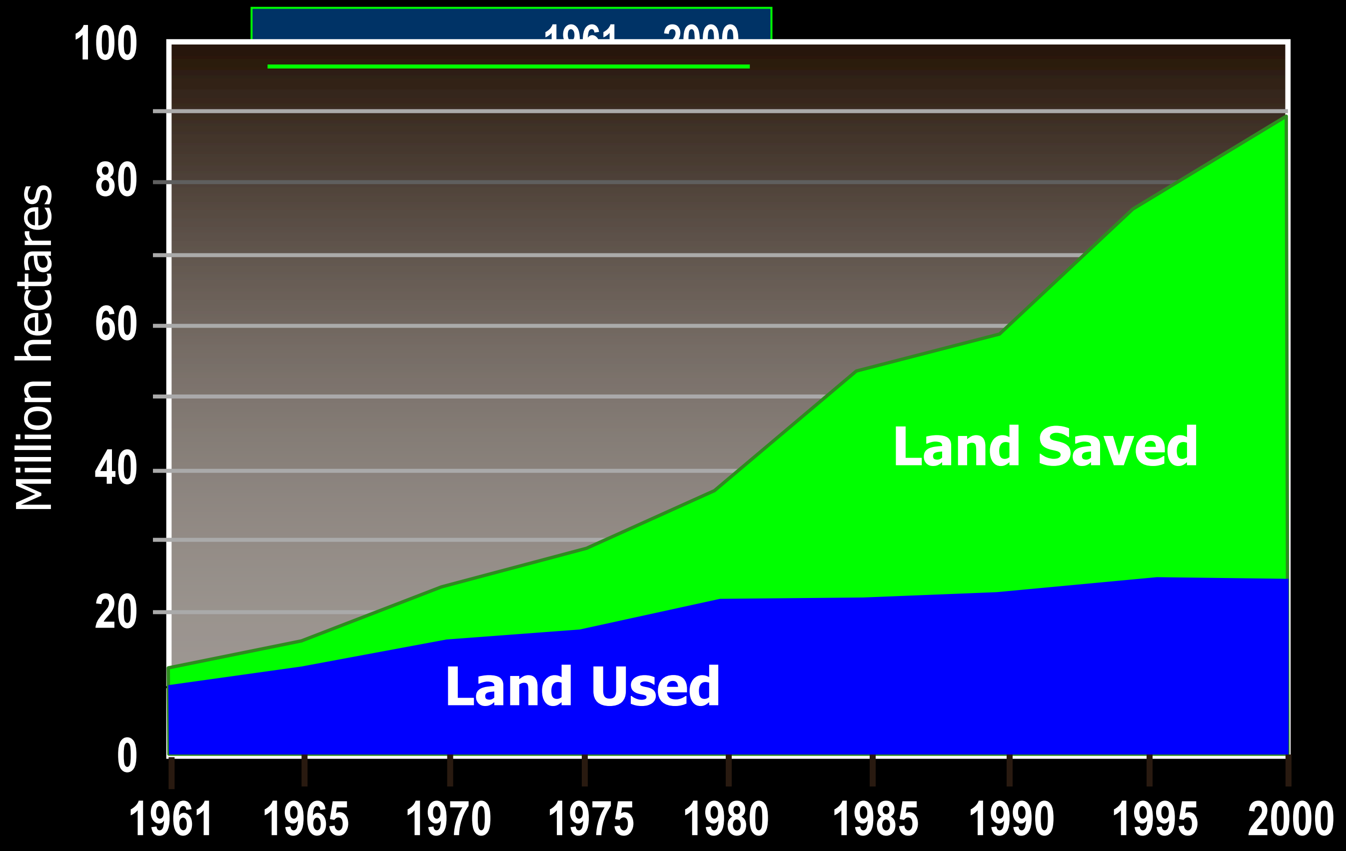
ww.co2.earth

Urban land vs Cropland



Amundson et al., 2015, Science

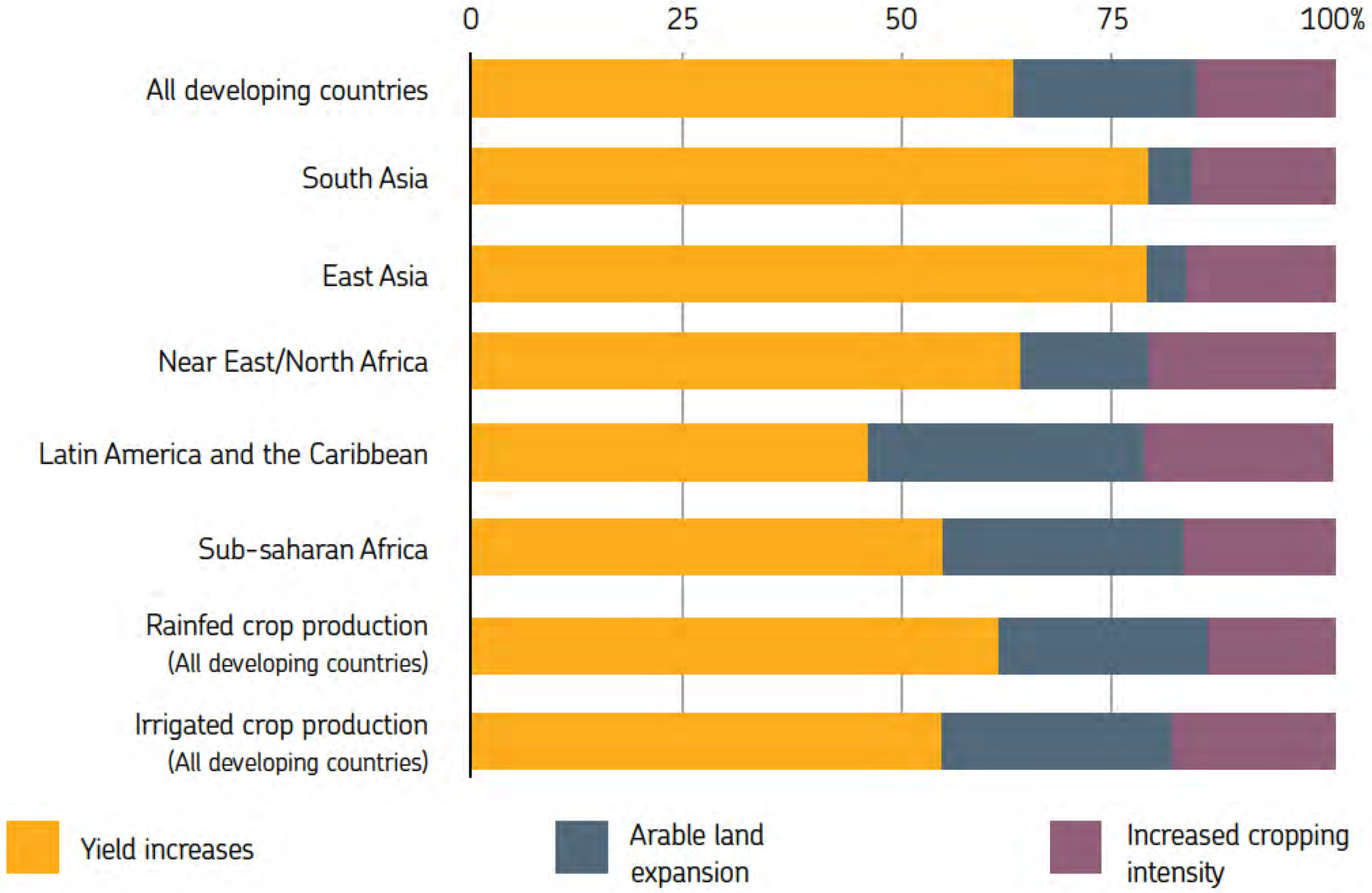
Indian Wheat Production—Area Saved Through Adoption of High-Yield Technology



Source: FAOSTAT

Increase in agricultural production as a percentage of the determining factor

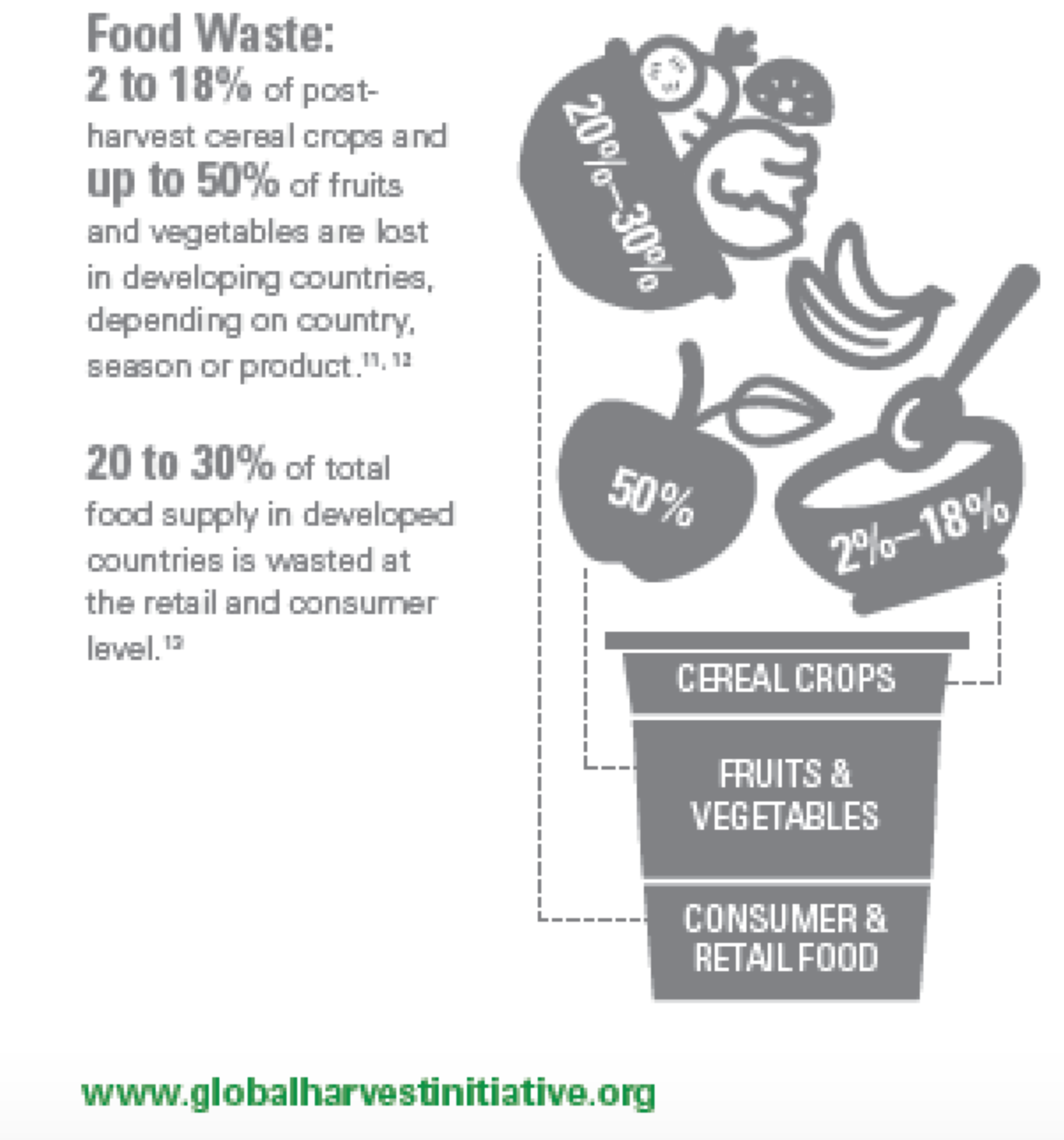
Source Barilla

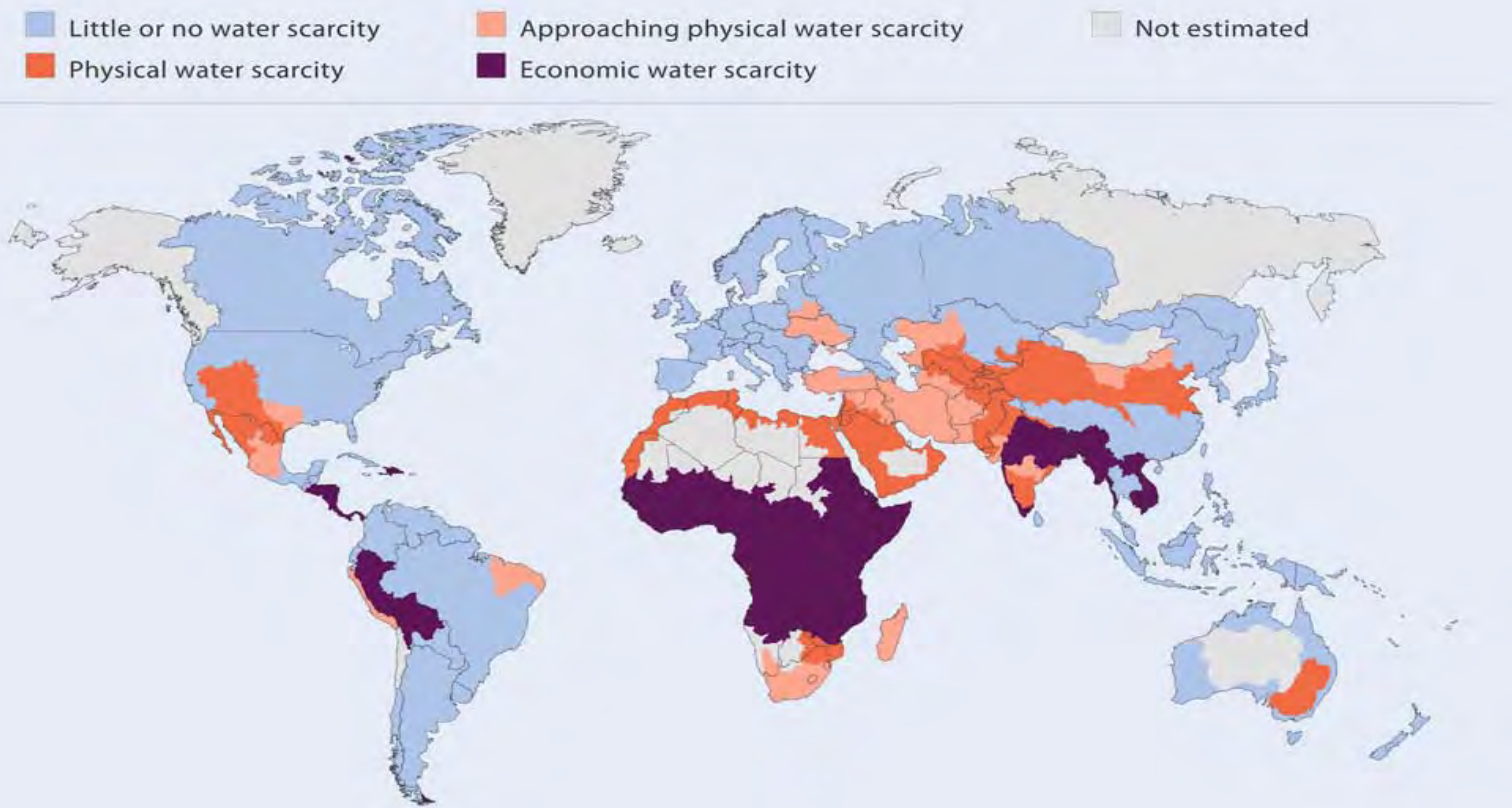


Food waste

Roughly one-third of the edible parts of food produced for human consumption gets lost or wasted globally, which is about 1.3 billion ton per year.

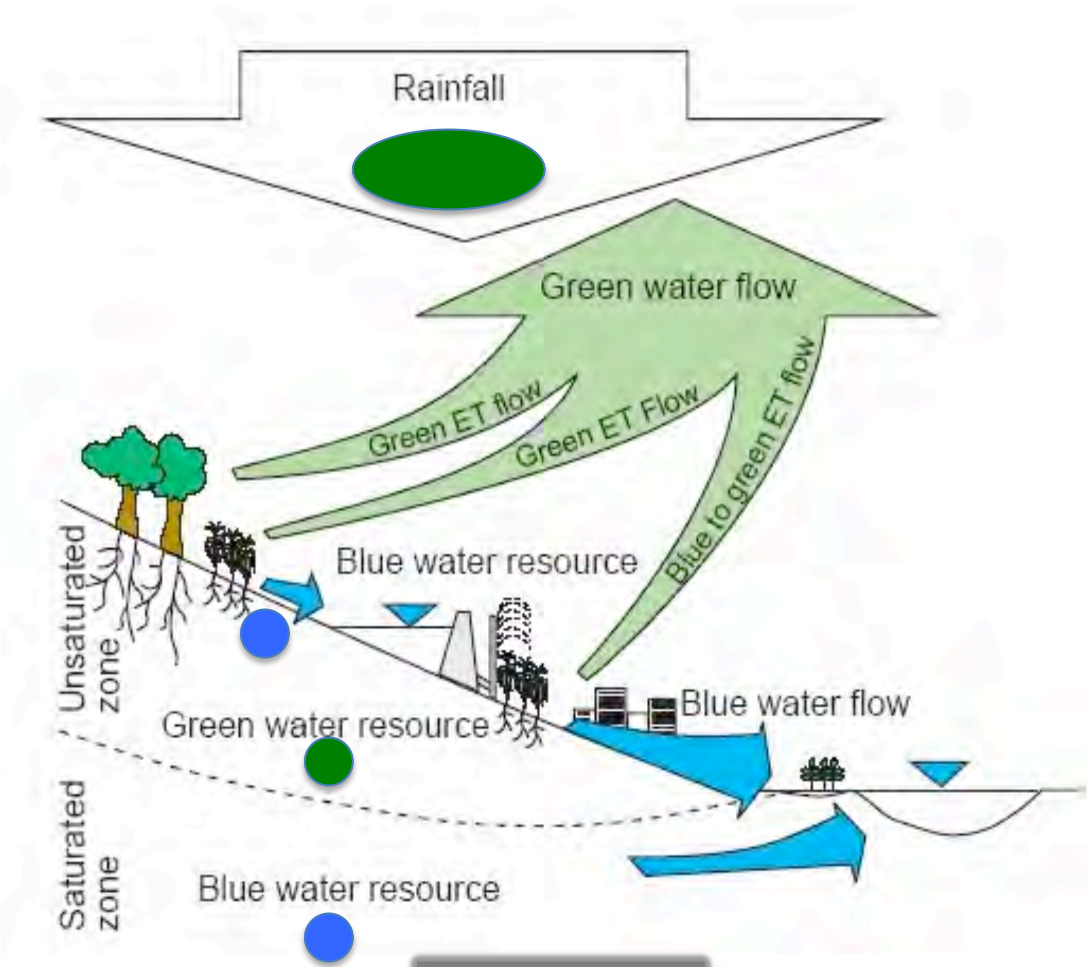
If food waste was a country, it will be third biggest emitter after the US and China




Little or no water scarcity
Approaching physical water scarcity
Not estimated
Physical water scarcity
Economic water scarcity

Water Footprint

Green Water



Blue Water

Grey Water

Water Footprint of foods

1 pound (0.5 kilograms) of beef requires:

1,799

gallons (6,810 liters) of water

6.6 pounds (3 kilograms) of grain for feed, plus irrigation water

36.2 pounds (16.4 kilograms) of roughage or grasses for feed, plus irrigation water

18.6 gallons (70.5 liters) of additional water for drinking and processing

2500 liters of water (Green and Blue water)

70 liters of water (Green)

90 liters of water (mostly Green)

Breakthroughs in Agriculture

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1900s Mechanization

1950s Fertilizer

1990s Biotechnology

2010s Data Science

Robots

Satellites

Big Data

Drones

Data Analytics

Sensors

Omics

Microbiomes

Digital Twins

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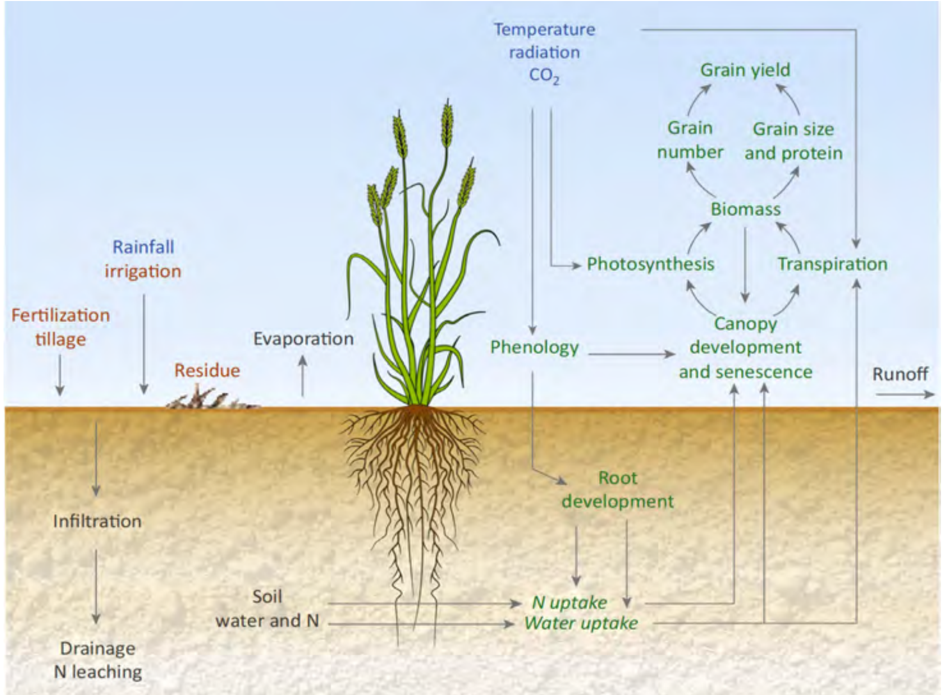
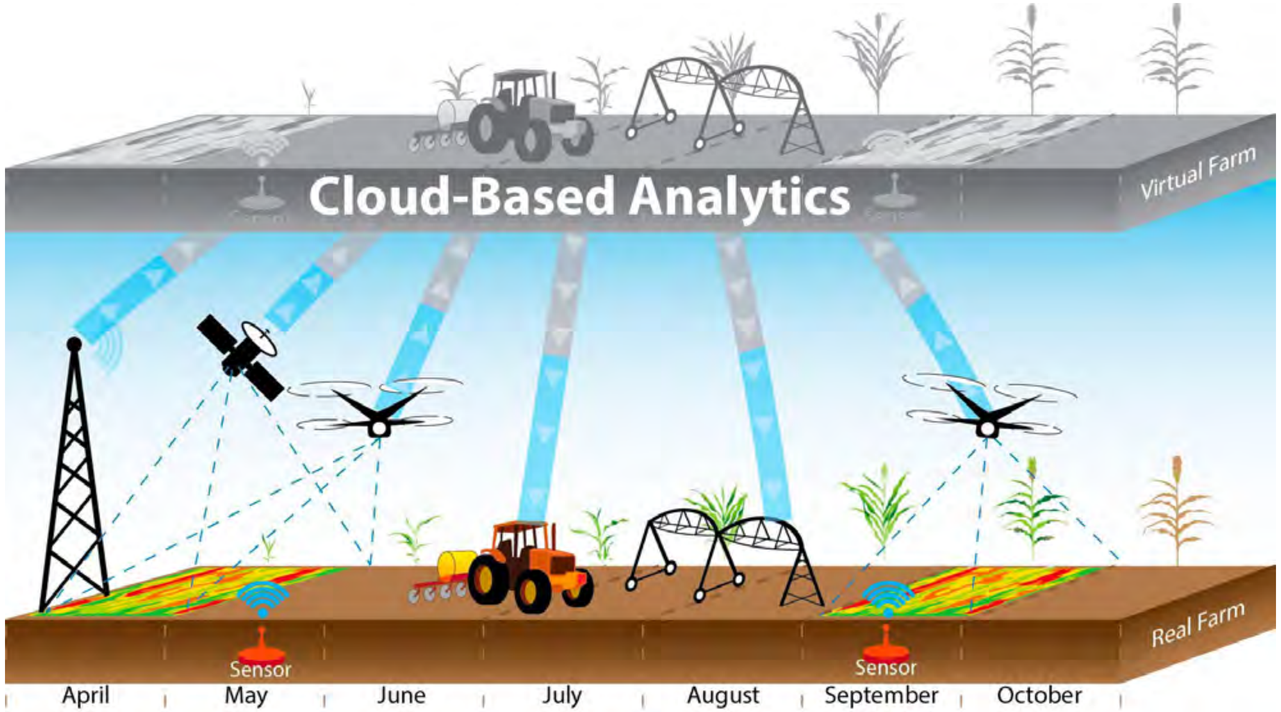
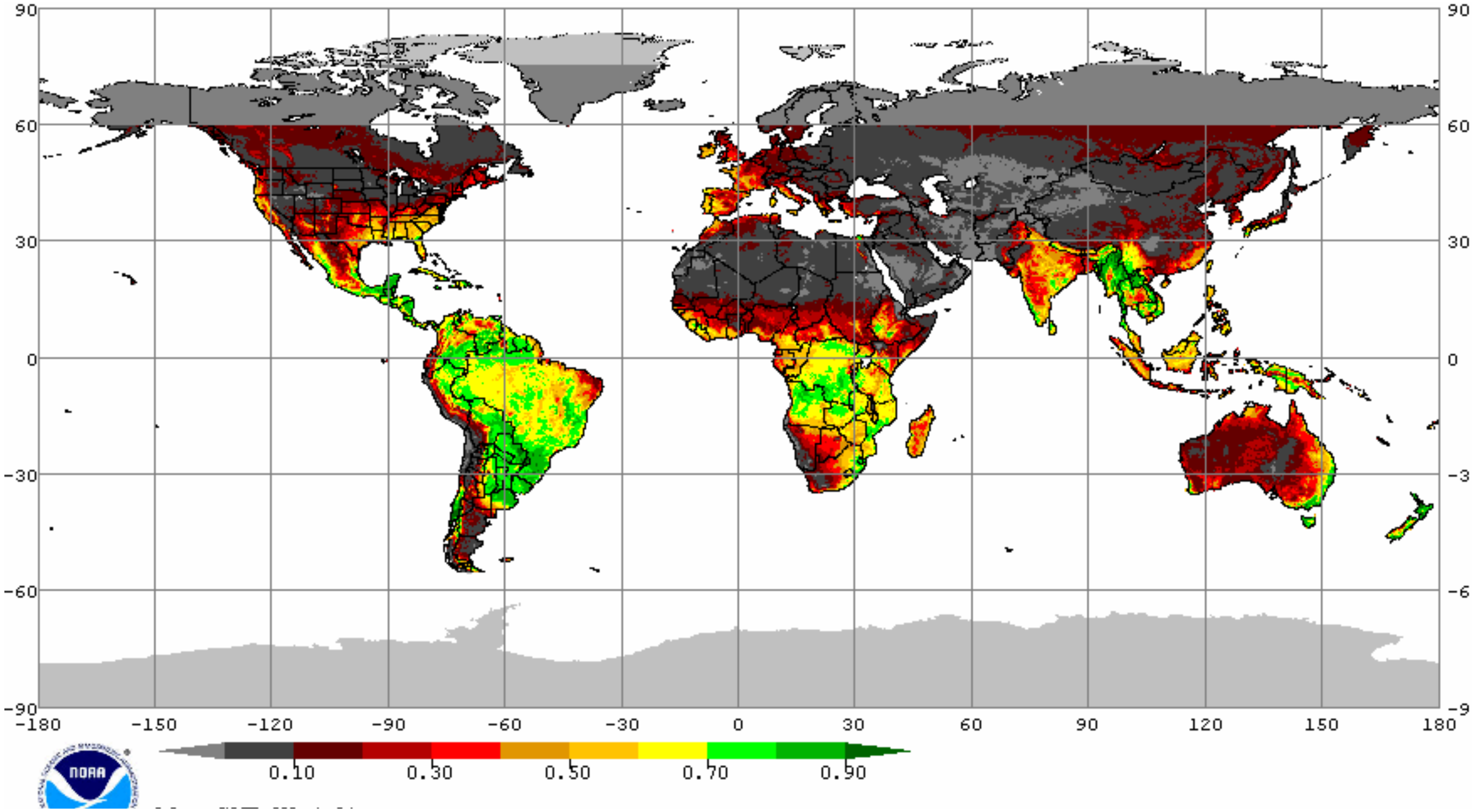
a bridge between the physical and digital world to promote innovation and performance





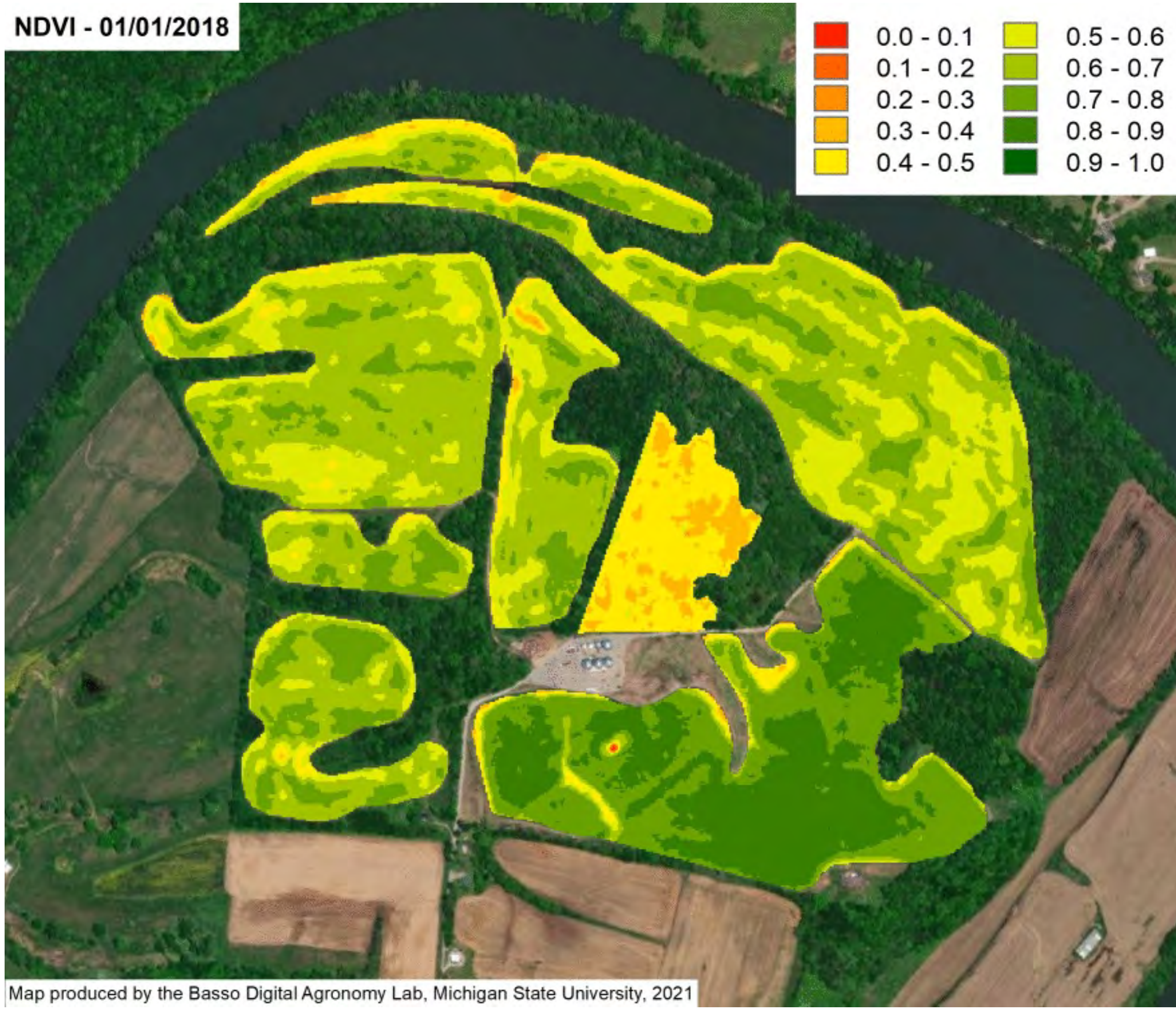
Circular Bioeconomy

Weekly changes of remotely sensed net primary productivity



Detecting practices and changes from satellite

Daily satellite images from 2018 to 2020



US Crop land

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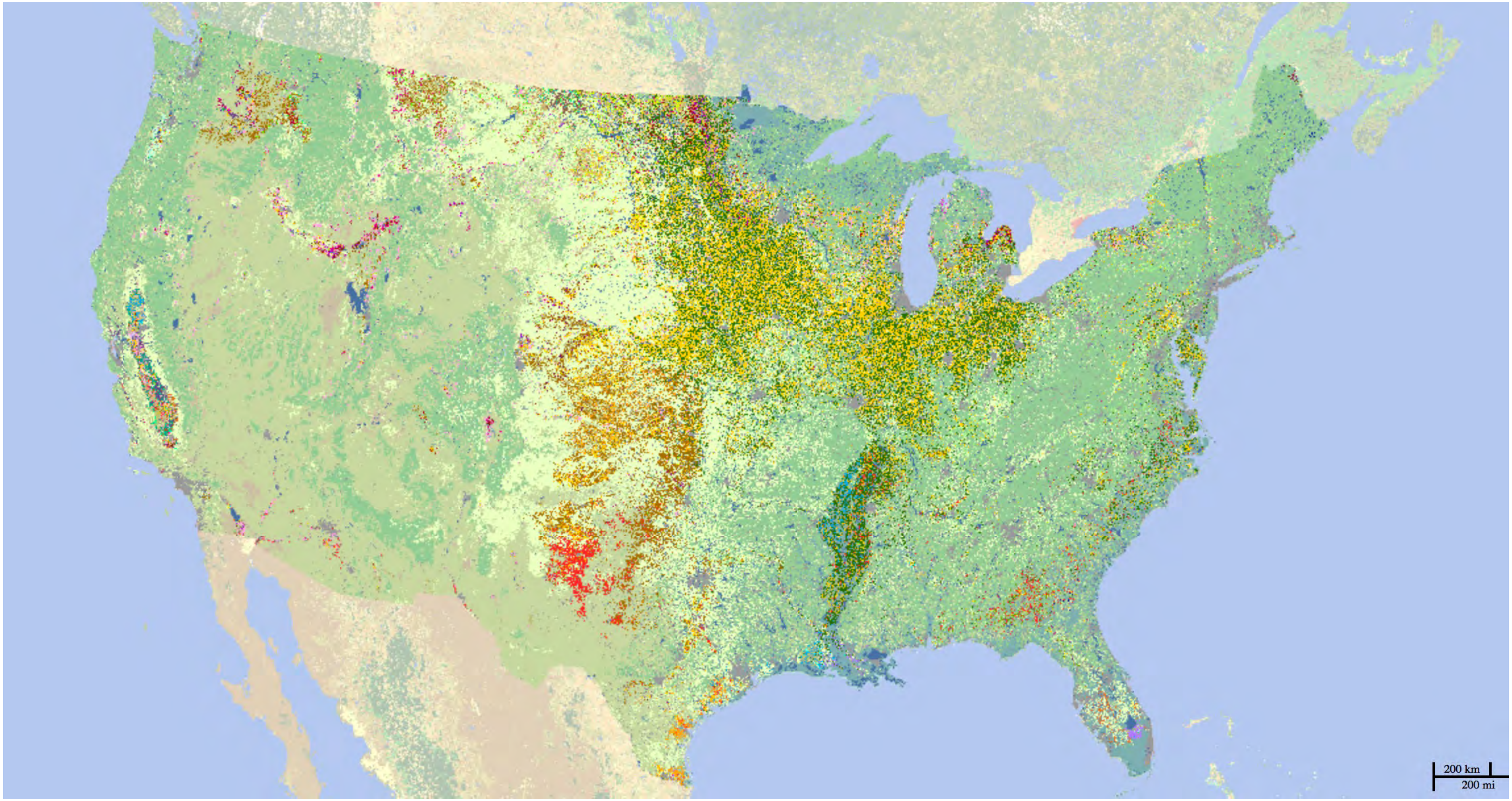


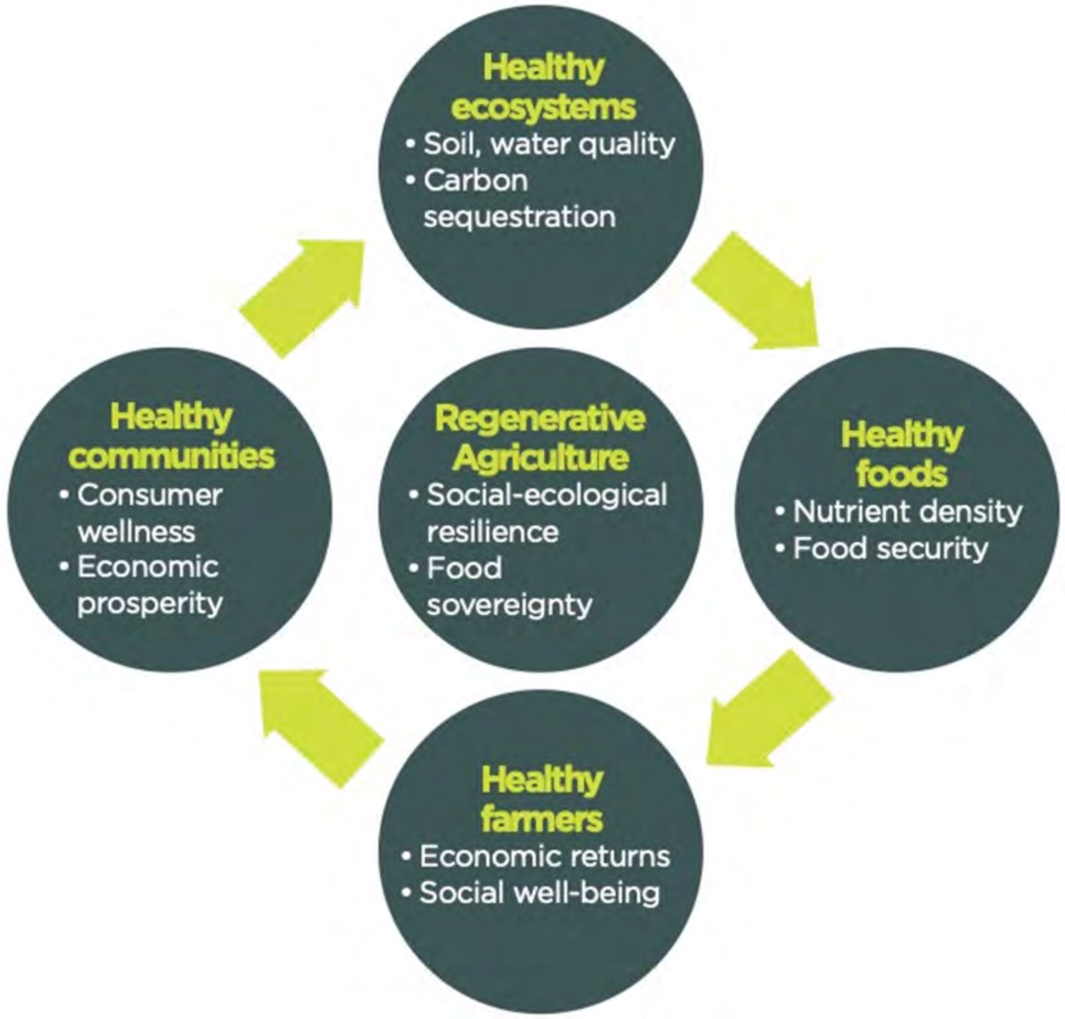
Regenerative Agriculture and One Health

Key principles

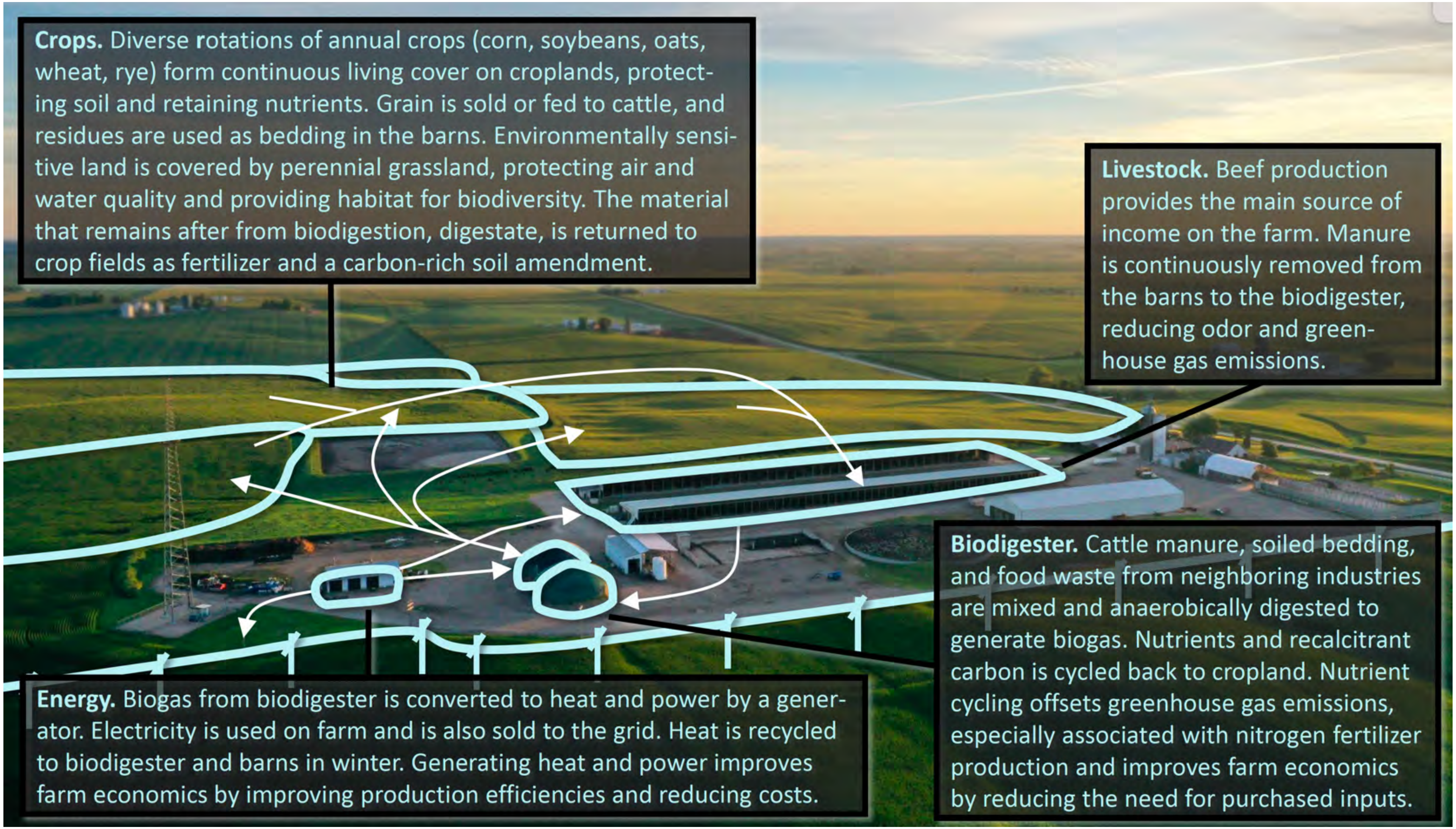
- High diversity (5 phase rotation)
- High circularity (regenerative nutrient cycles, compost))
- Animal integration (grazed forage, crop residues)
- Forever green (cover crops, perennials, agroforestry)
- Precision Conservation on consistently low-yielding areas
- Continuous no-till, precision technologies

Key Ecosystem Services

- Greenhouse gas mitigation (CO_2, N_2O, CH_4)
- Soil carbon sequestration
- Biodiversity conservation (pollinators, habitat)
- Soil health, water quality
- Profitability, farmer well-being



Center for Regenerative Agriculture
Michigan State University



Schulte et al., 2022, Nature Sustainability

A digital revolution in Agriculture

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THE FUTURE OF AGRICULTURE

A technological revolution in farming led by advances in robotics and sensing technologies looks set to disrupt modern practice.

BY ANTHONY KING

Forbes

EDITORS' PICK | 6,500 views | Apr 22, 2020, 06:13pm EDT

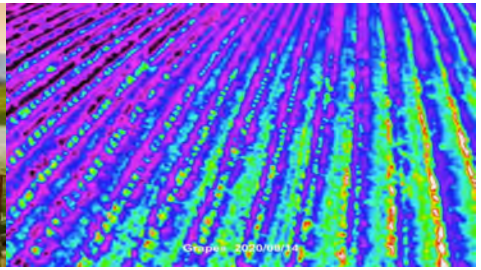
Welcome To The New World Of Digital Agriculture

Multi-Hybrid Planting

Digital Agriculture

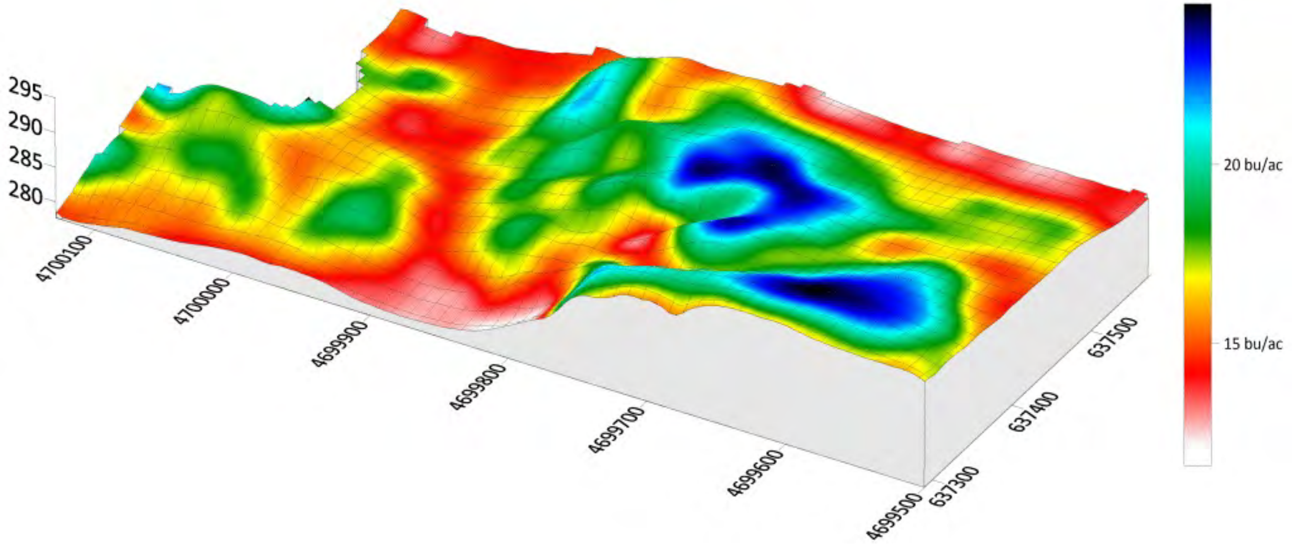


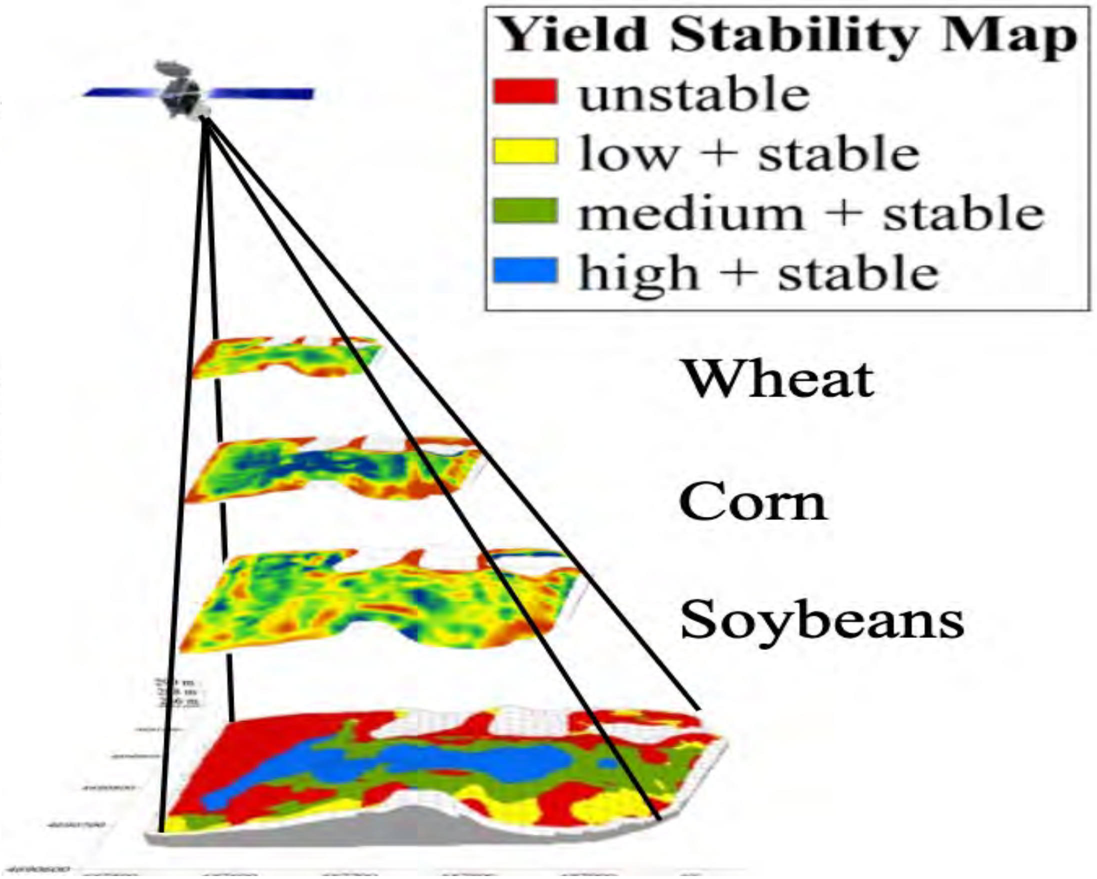




150 bushel/acre ~ 10 ton/ha

Soybeans 2009



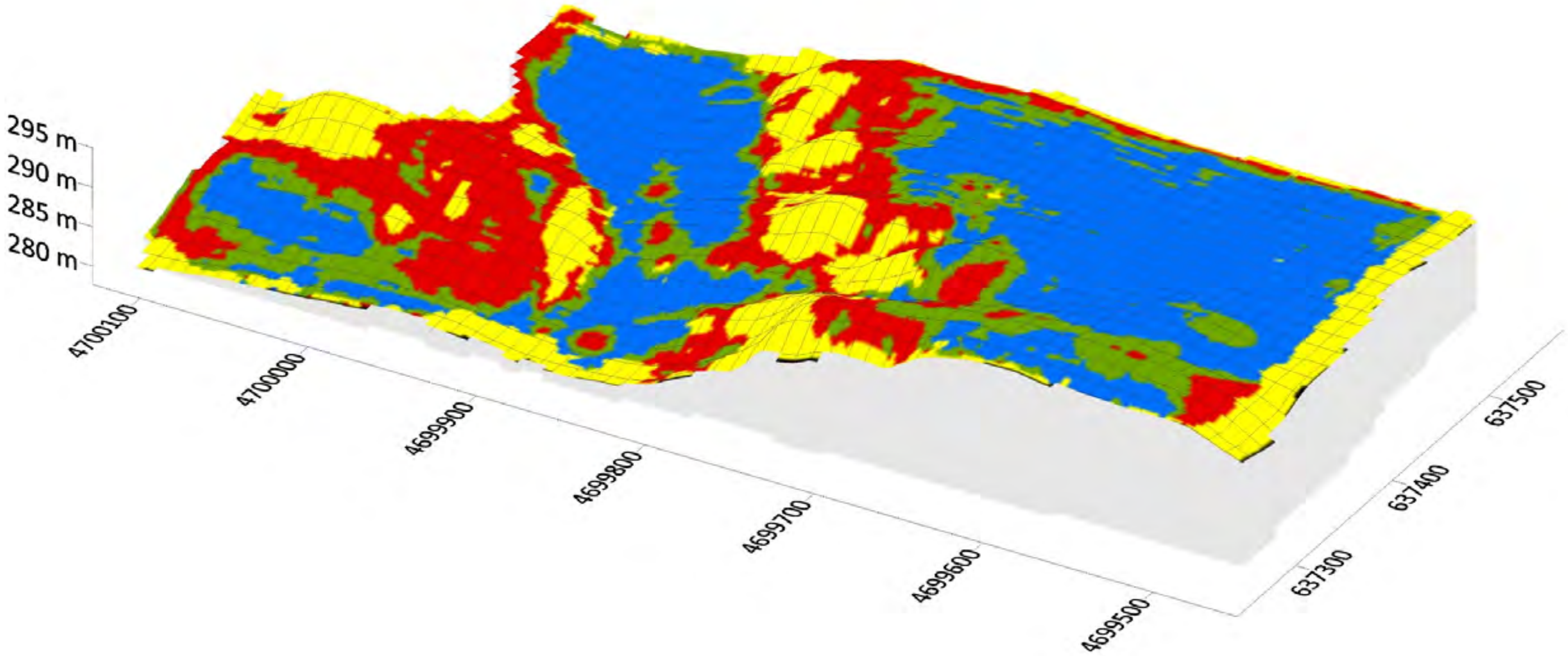


68% of US corn was harvested with combined equipped with yield monitor
45% of the corn area was yield mapped (Lowenberg-DeBoer and Erickson, 2019, *Agron J.*)

Thermal Stability

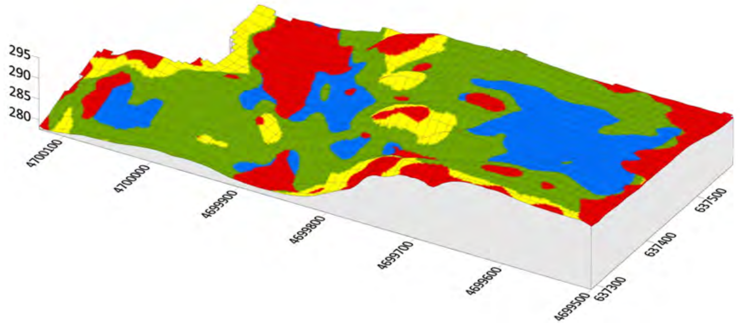
Thermal Stability Map
all 40 images

- unstable
- cold + stable
- medium + stable
- hot + stable



Yield Stability

- unstable
- low + stable
- medium + stable
- high + stable



Plant health stability

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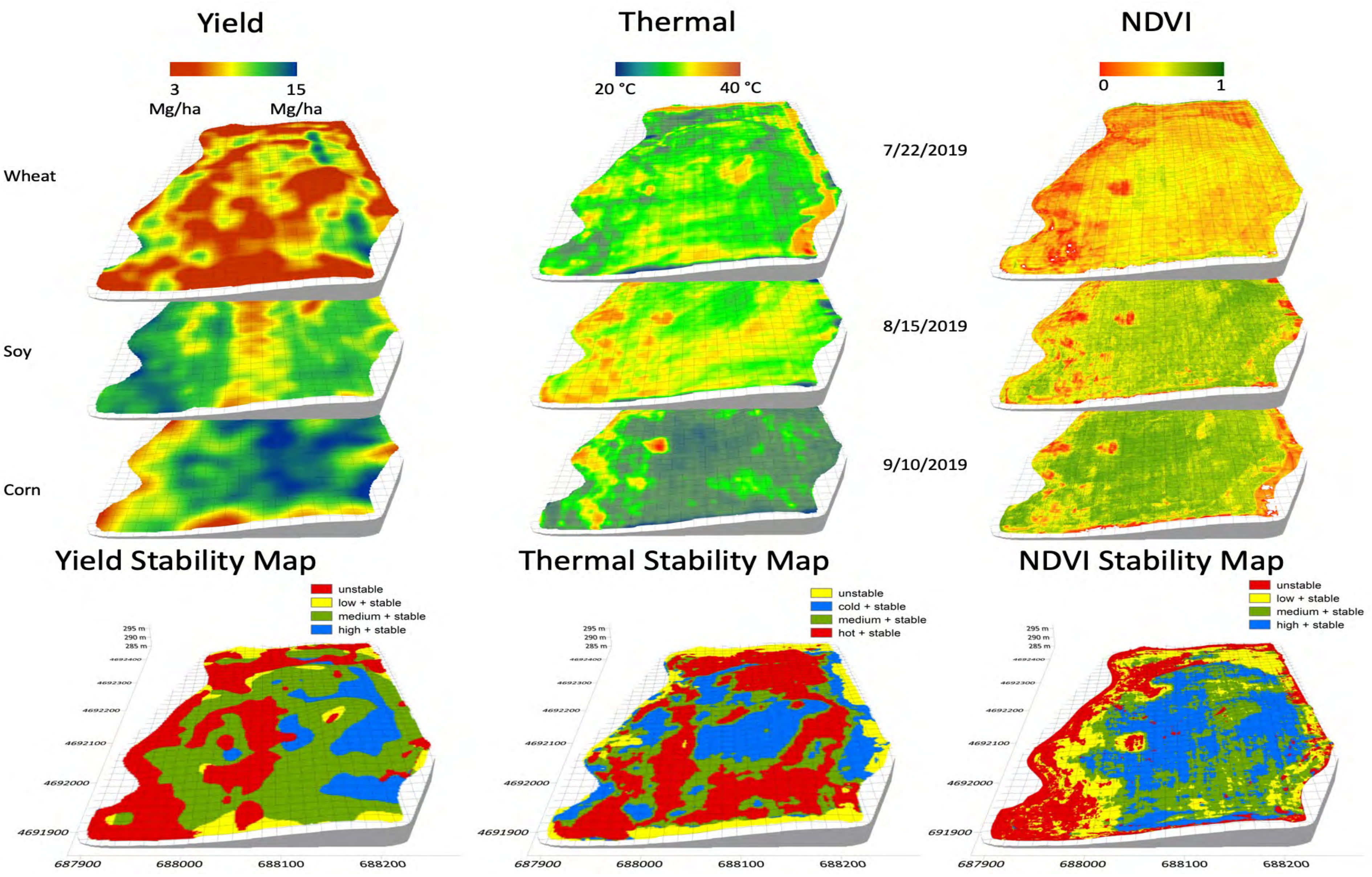
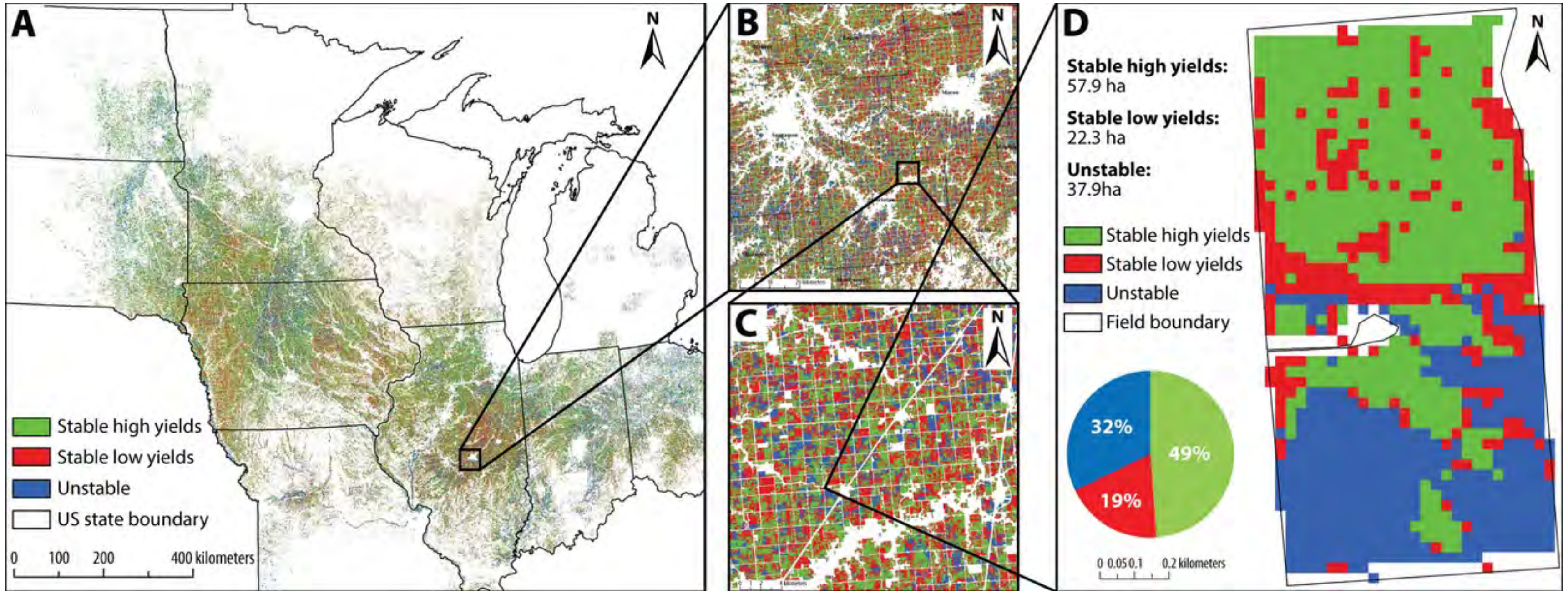


Subfield yield spatial and temporal variability



Crop and yield stability maps for (A) 10 Midwest states; (B) 10,000 km2 subregion; (C) 196 km2 subregion; and (D) 118 ha

Methods:

- 10 years NASA Landsat images
- Common Land Units (field boundaries)
- Crop data layers (corn and soybeans)
- NASS Arms (Fertilizer rates)

Impacts

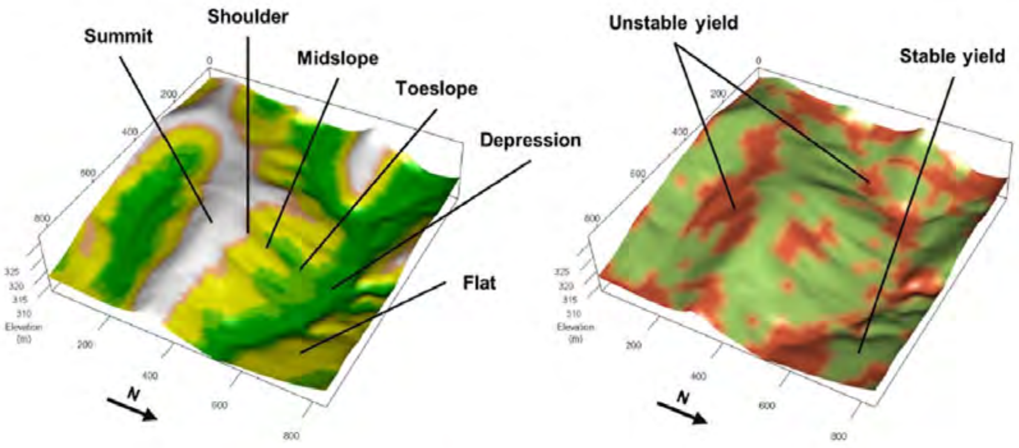
- ~ 1.4 Tg N yr $^{-1}$ of N fertilizers is lost to the Gulf of Mexico
- ~ 700 Million US$ yr $^{-1}$ wasted from crop unused fertilizers
- 1.1 Billion Giga Joule of energy lost
- 7 Million tons yr $^{-1}$ CO_2 lost to the atmosphere

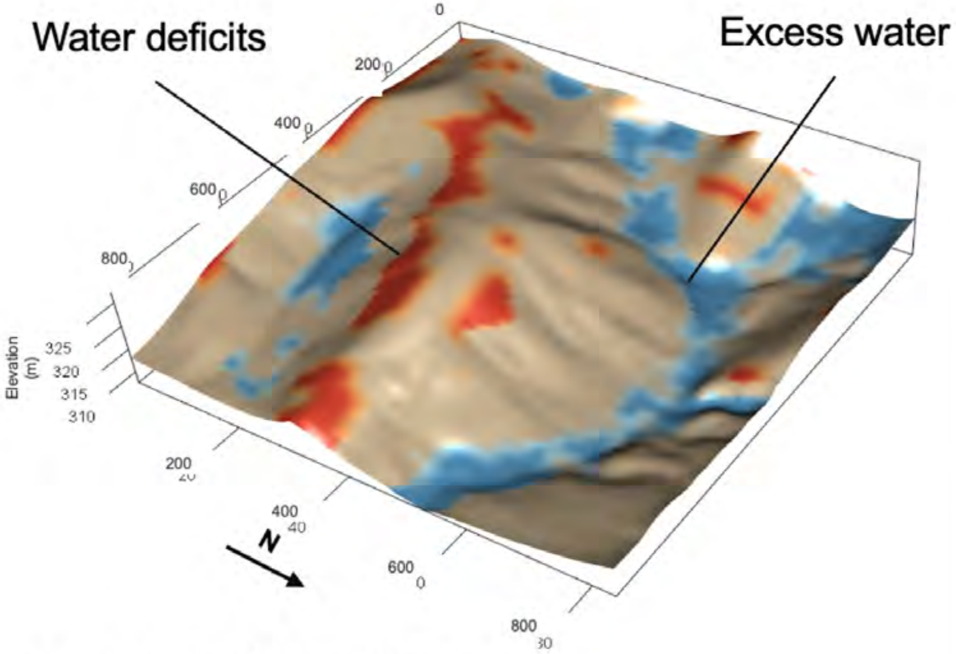
Subfield productivity across 80 M acres (~ 8 Million fields)

Yield Stability	Share of area	Nitrogen-use efficiency
Stable, High yields	48%	75%
Stable, Low yields	25%	45%
Unstable	27%	58%

Basso et al., 2019; Martinez-Feria and Basso. 2020

Landscape position modulates interactions between soil-plant-climate

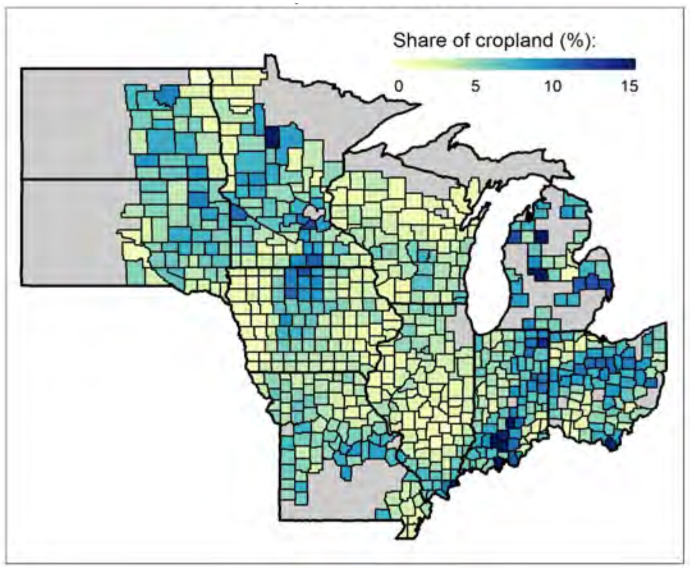




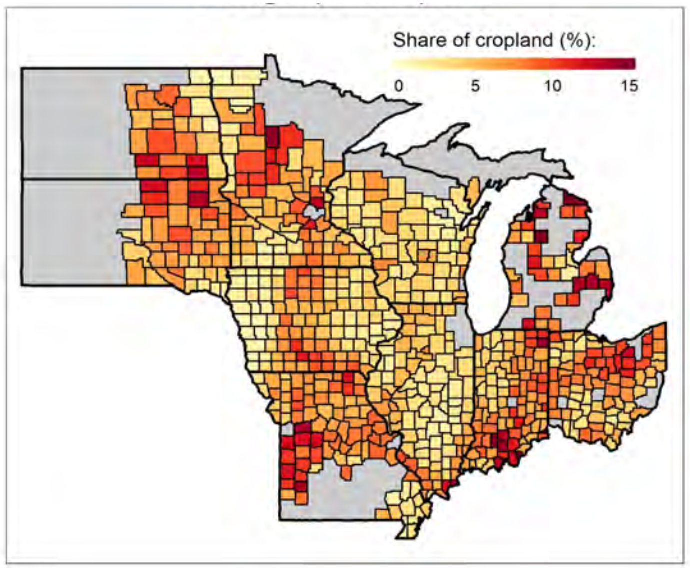
Martinez-Feria and Basso, 2020


Source: Sotirios Archontoulis

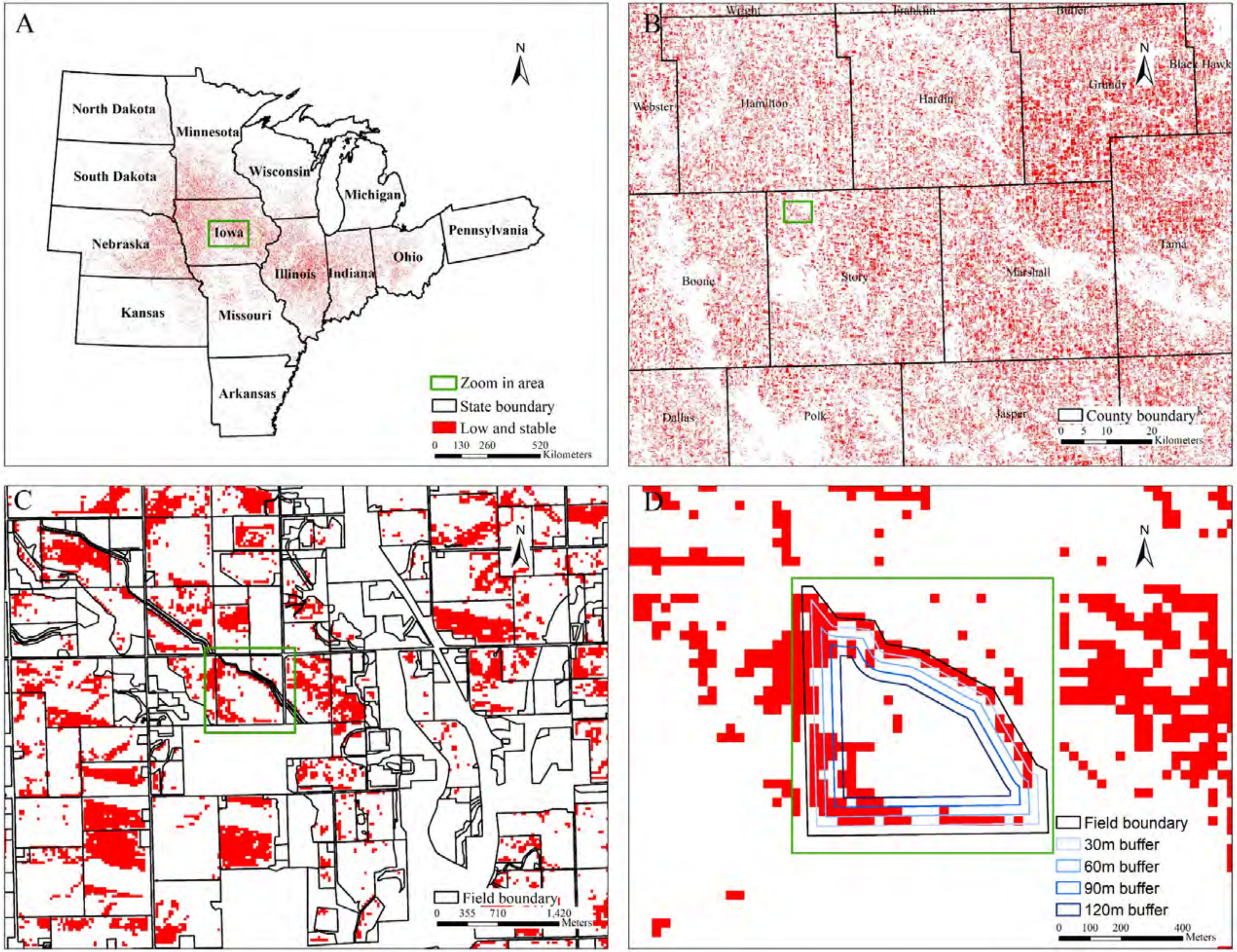
Unstable zones in lowland positions (prone to excess water)



Unstable zones in upland positions (prone to water deficit)



Low yielding areas across 80M acres



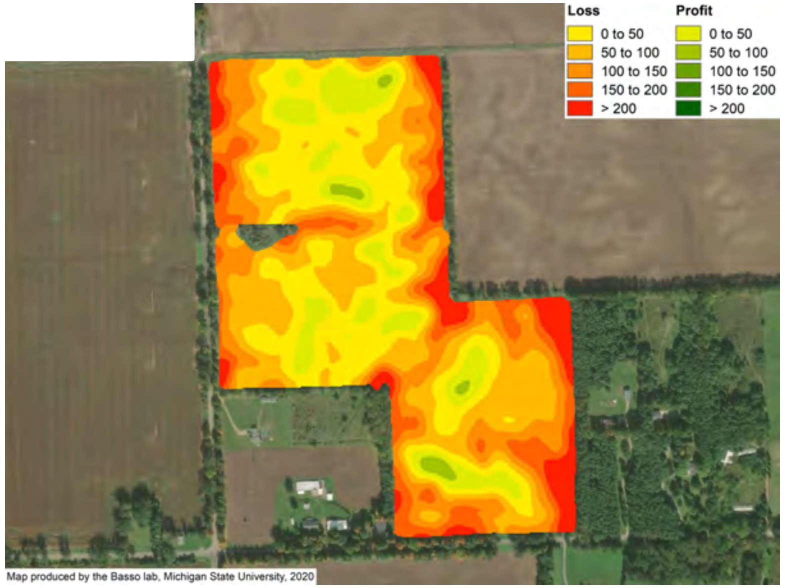
23 Million acres of low productivity of which 15.5 M acres in-field and 7.5 M acres on the edge;

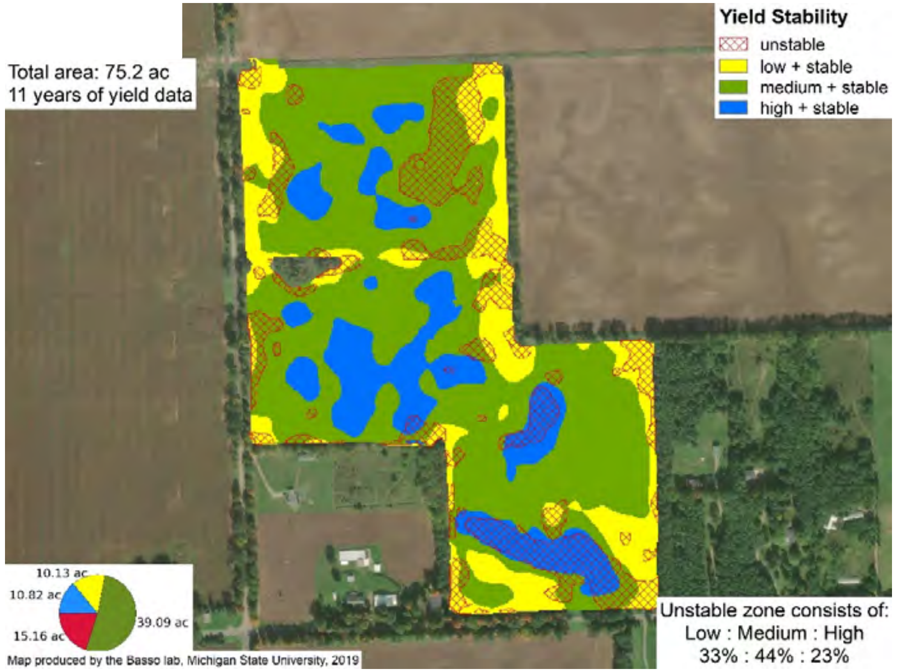
Managing LS will lead to significant savings in:

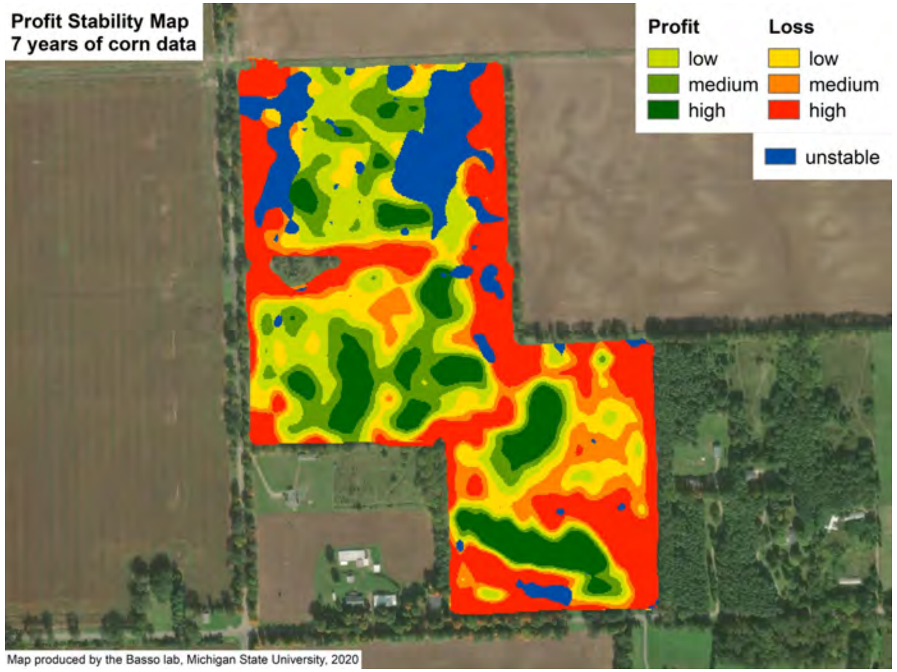
- NO_3 leaching reduction (1Tg/yr)
- GHG emissions (3-5ppm CO_2/yr)
- C fixation (~20Ton C/yr),
- Biodiversity associated benefits

Basso et al. 2023 in preparation

Profit Stability

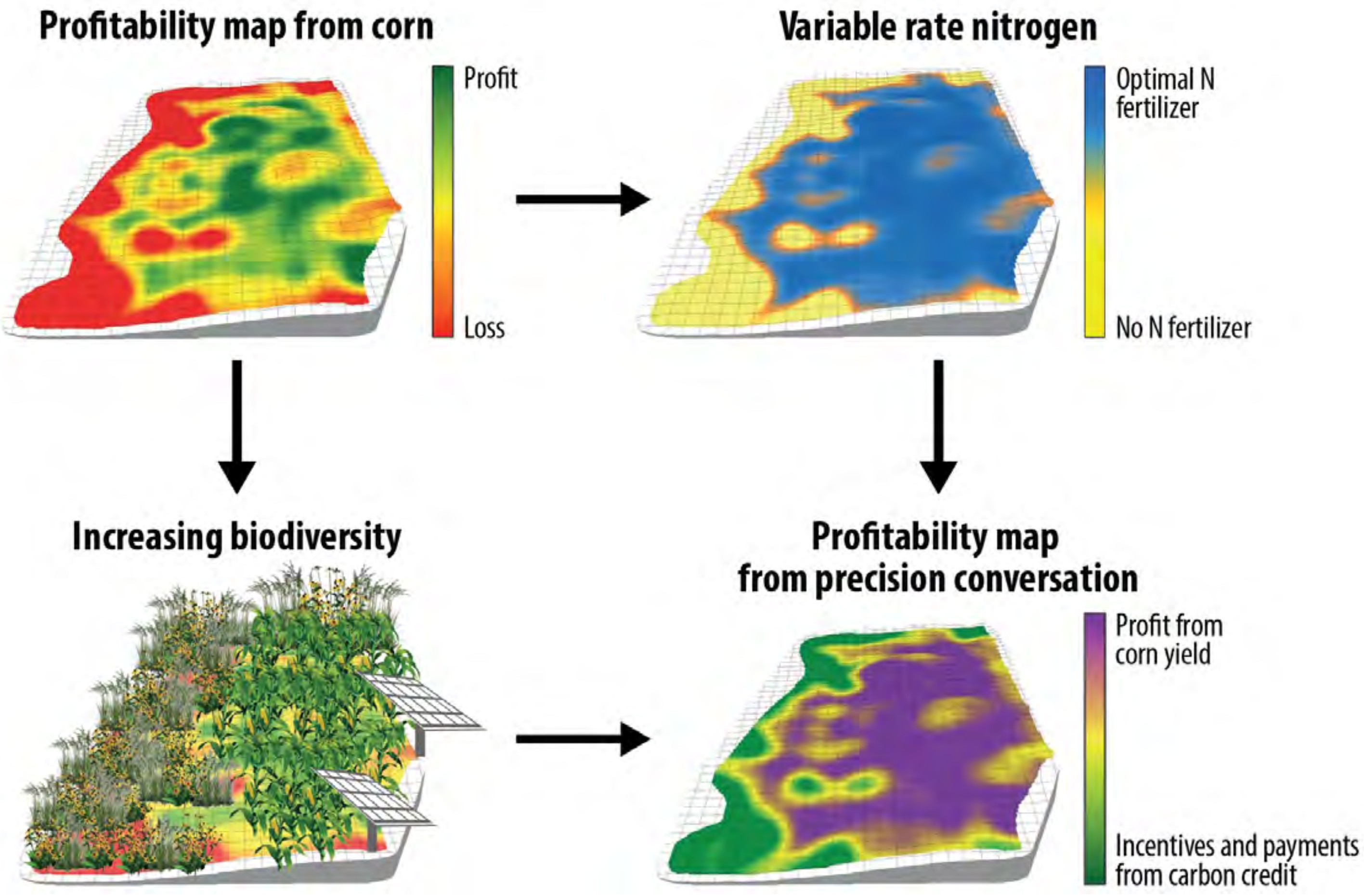


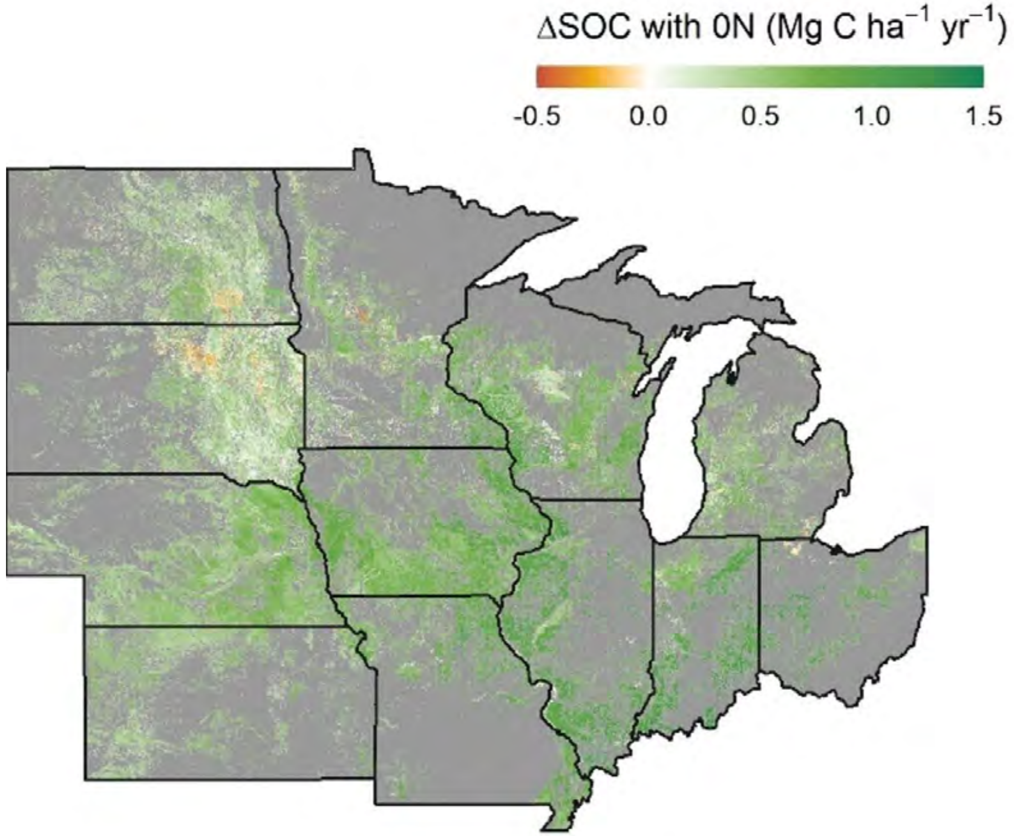




Low $50
Med. $100
High $200

Precision Conservation



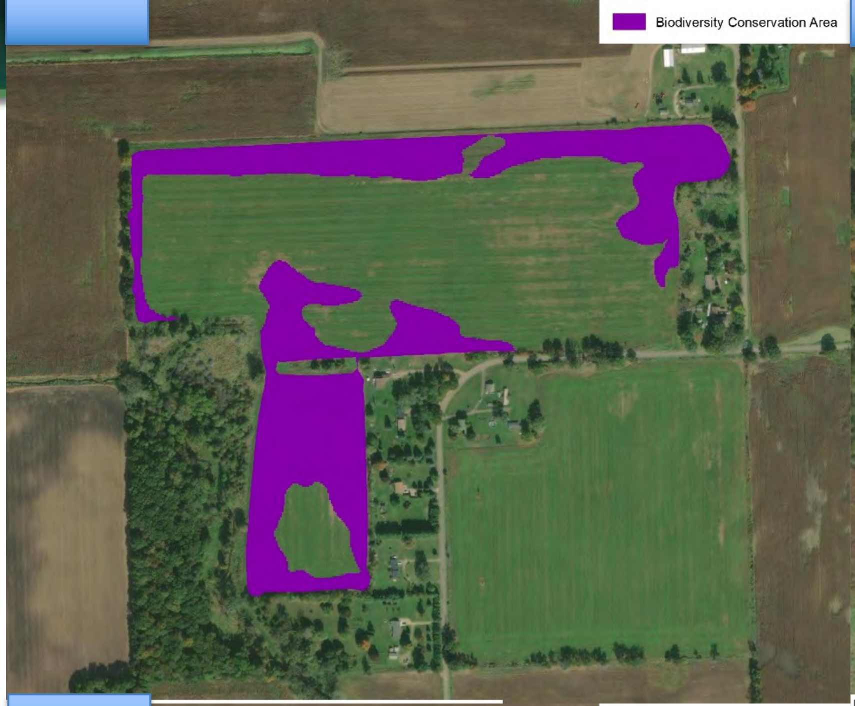


Planting switchgrass on marginal lands

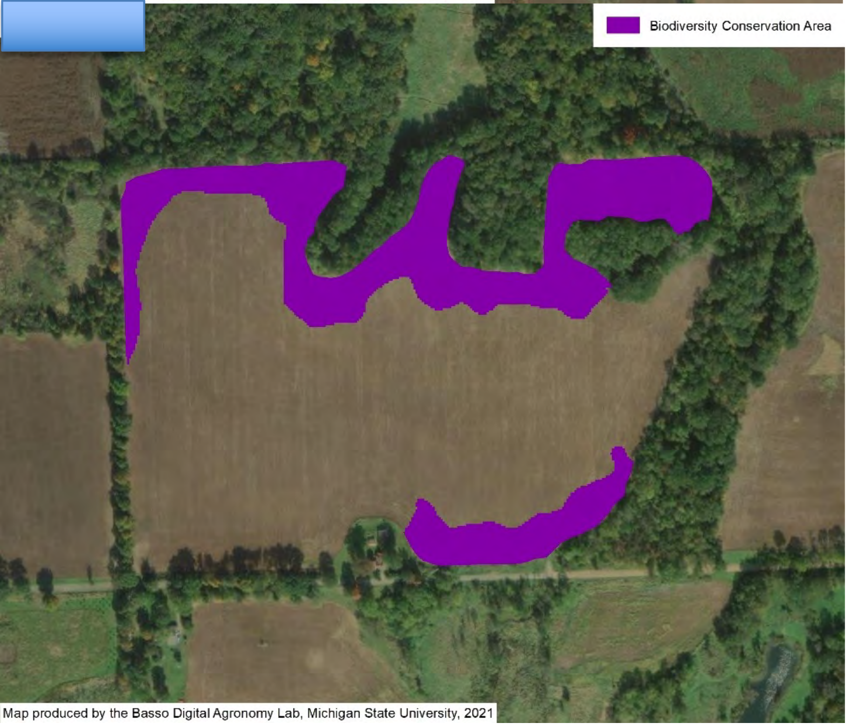
Basso, 2021 Nature Food;
Basso and Antle, 2020 Nature Sustainability

Martinez-Feria, Basso, Kim, ERL 2021


Biodiversity Conservation Area


Biodiversity Conservation Area


Biodiversity Conservation Area
Map produced by the Basso Digital Agronomy Lab, Michigan State University, 2021


Biodiversity Conservation Area
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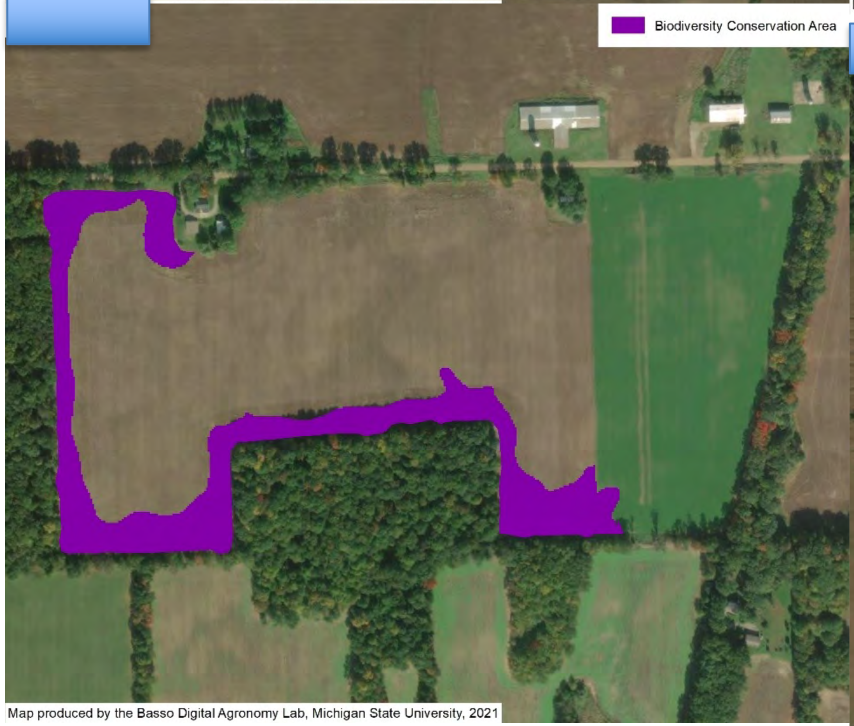
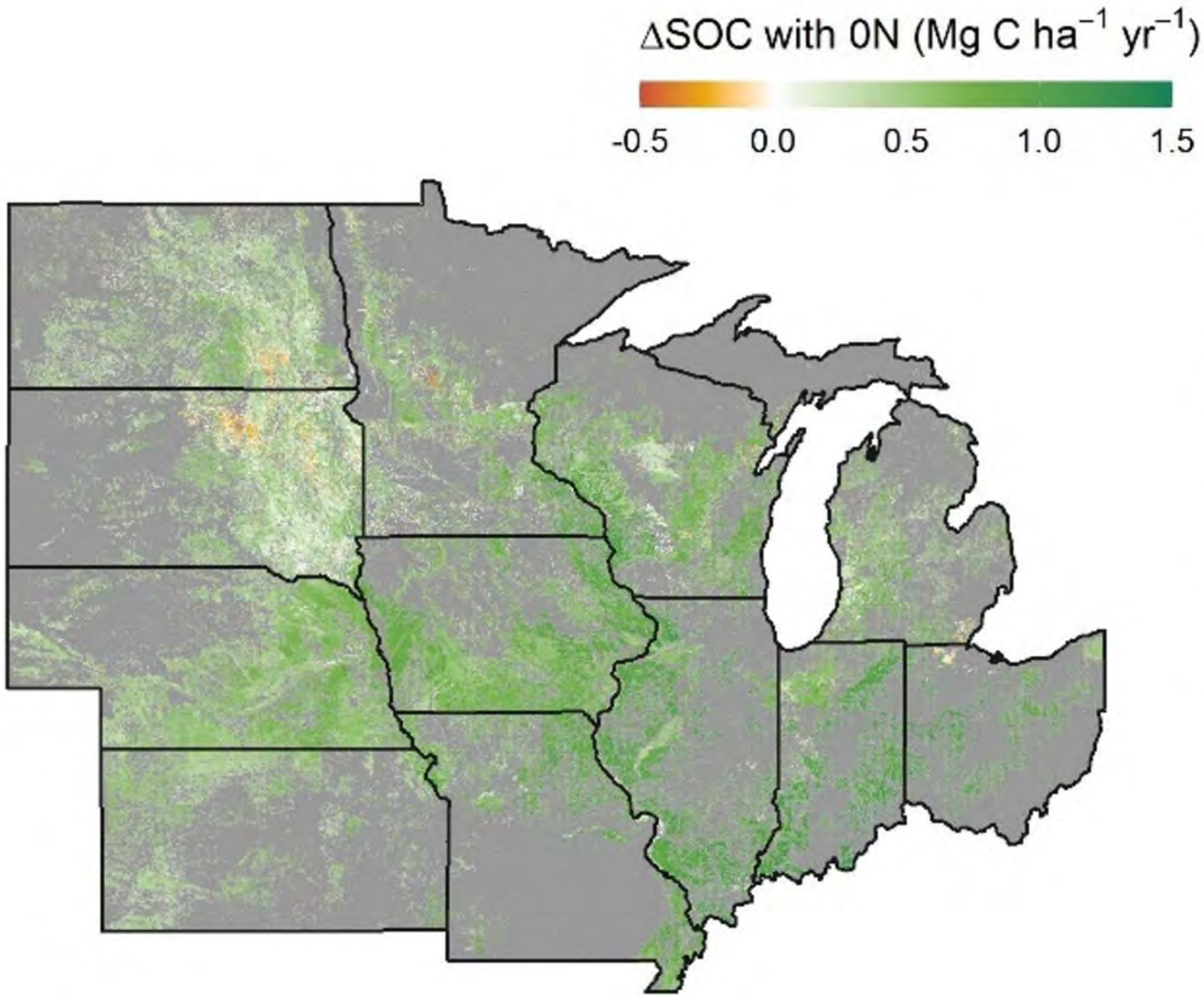
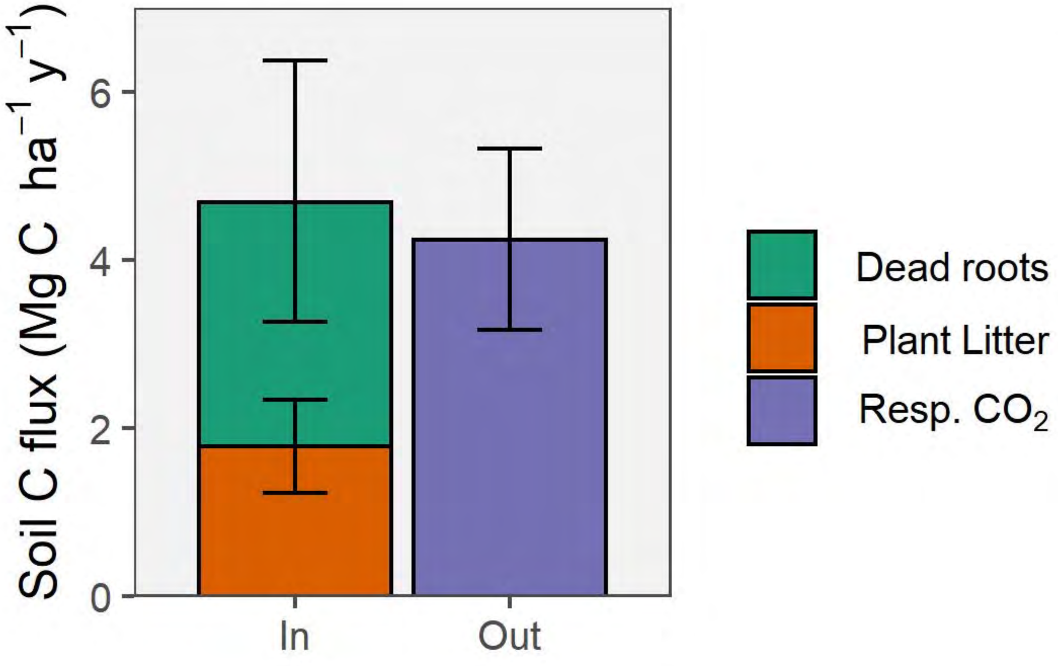

Biodiversity Conservation Area
Map produced by the Basso Digital Agronomy Lab, Michigan State University, 2021


Biodiversity Conservation Area
Map produced by the Basso Digital Agronomy Lab, Michigan State University, 2021

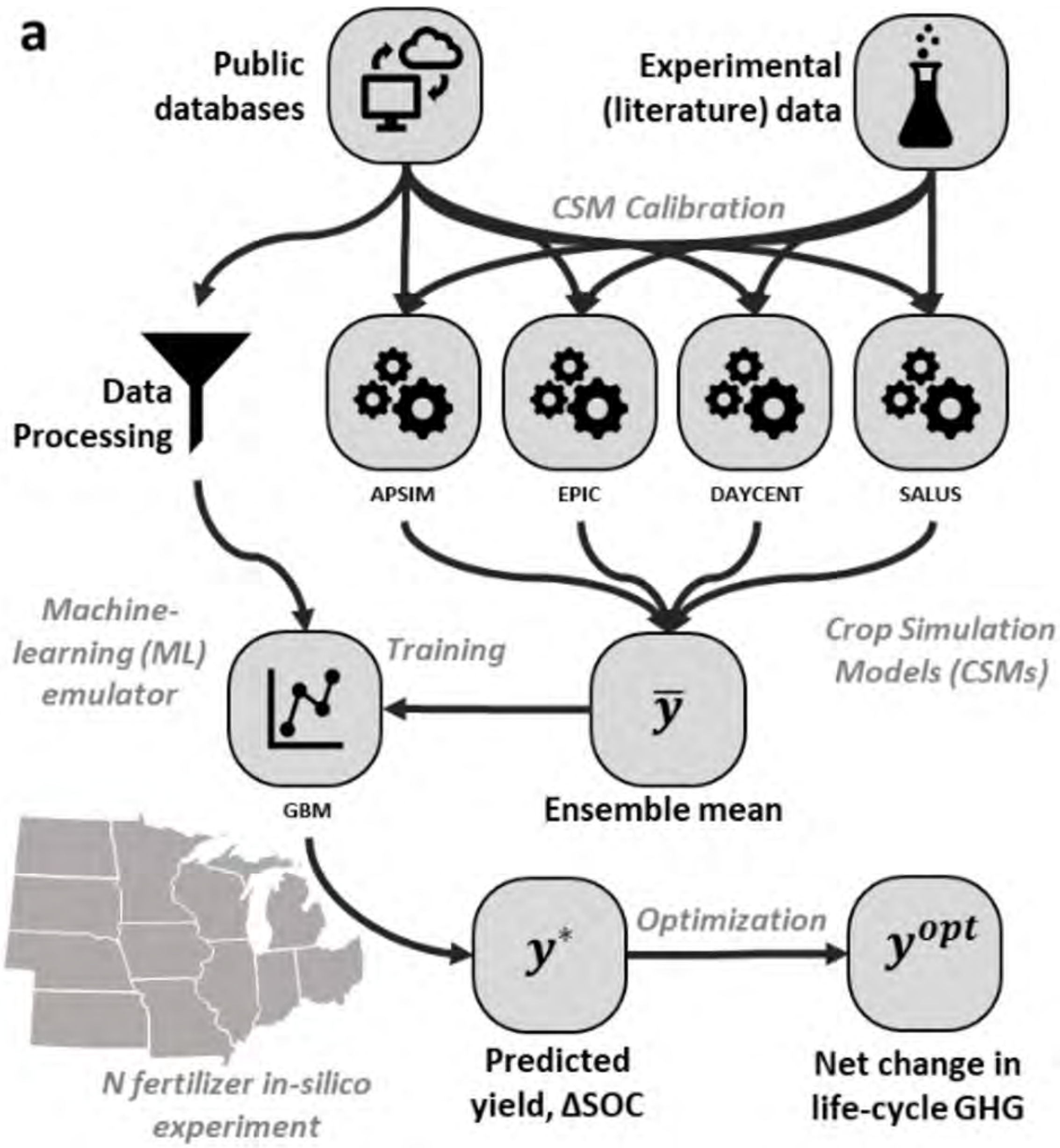
Changes in Soil Organic Carbon on marginal lands

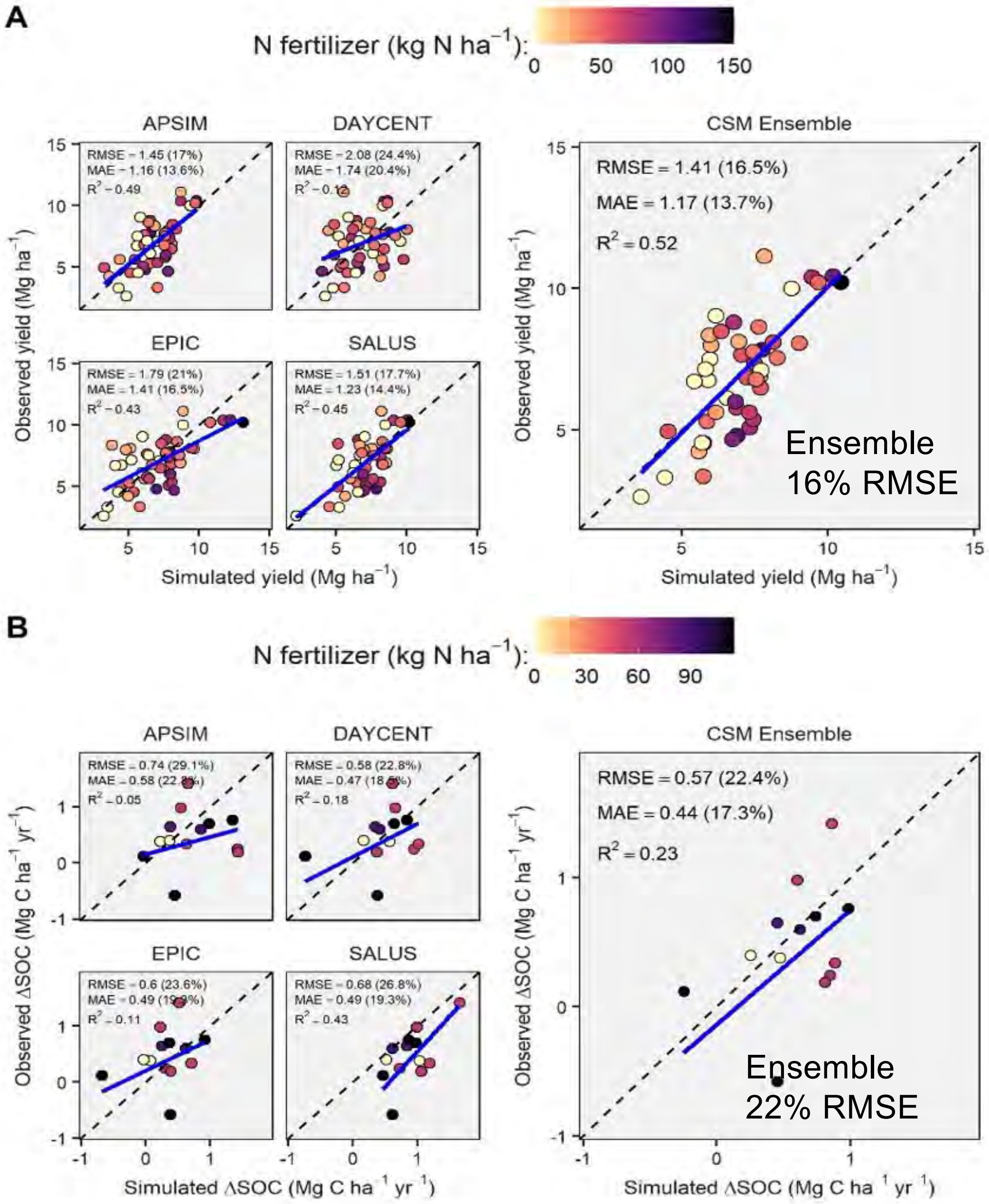




Martinez-Feria and Basso, GCB-B 2020

Multi model ensemble and ML emulators





Martinez-Feria, Basso, Kim, ERL 2021

Machine L earning vs process based models

Emulator: A statistical model that 'learns' the behavior of a more complex model (A.K.A Surrogate model or metamodel)

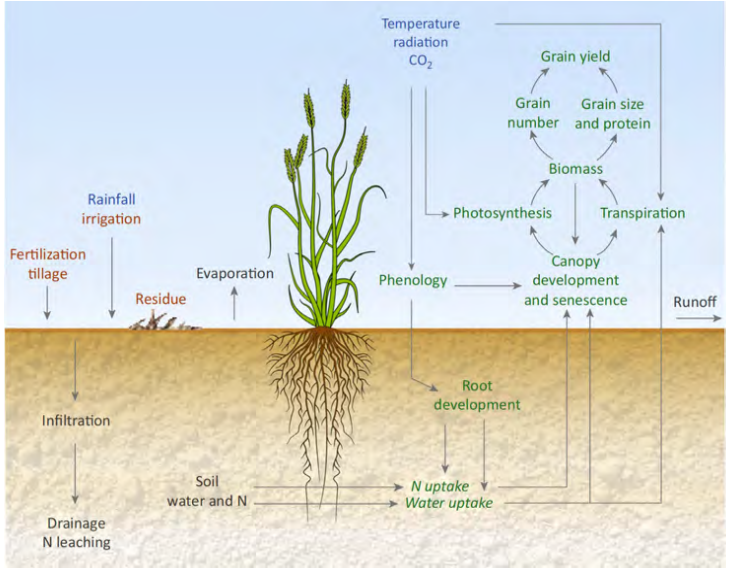
The Pros:

Fast and easy to run
Less computationally expensive

The Cons:

Potential loss of predictive power (propagated errors)
Data often missing

Crop models



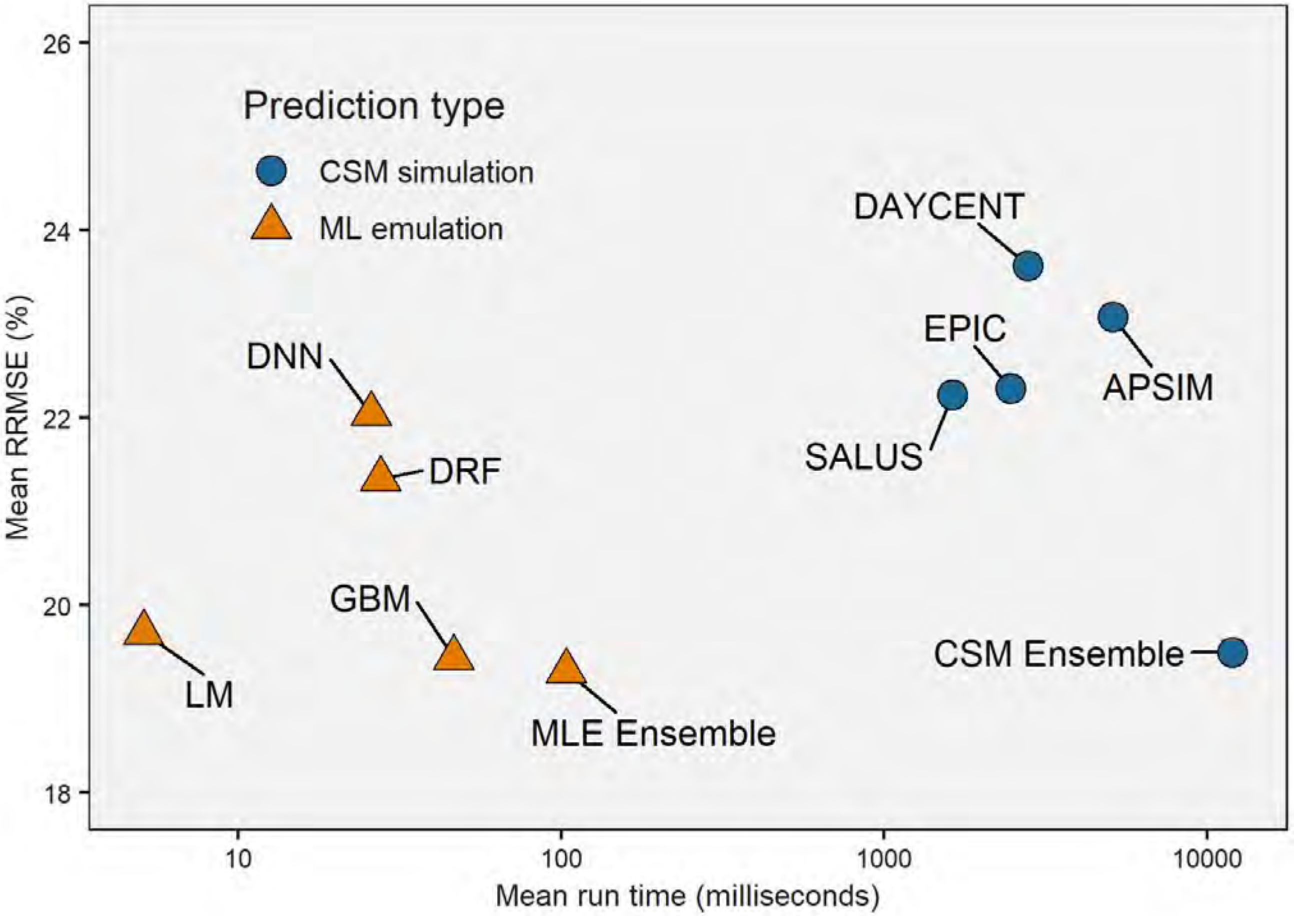
The Pros:

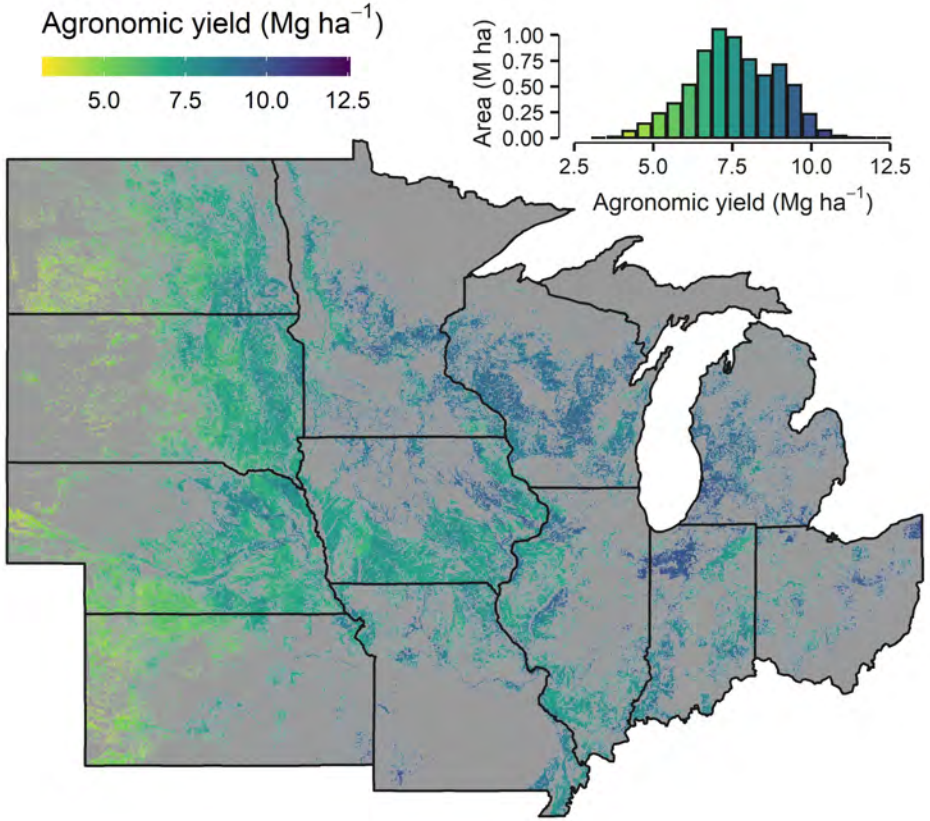
Multiple outputs (explanation)
Can deal with new/unseen environments
Good for hypothesis testing

The Cons:

Steep learning curve
Difficult to set up and (re)calibrate
Idiosyncratic (bias, model structure)
Computationally expensive (complex, slow to run on large scales)

ML emulators of ensembles perform better than single models and produce prediction >100 times faster





7 million ha @ 30 m resolution X 20 years predicted in less than 10 minutes

Martinez-Feria, Basso, Kim, ERL 2021

Geospatial systems approach

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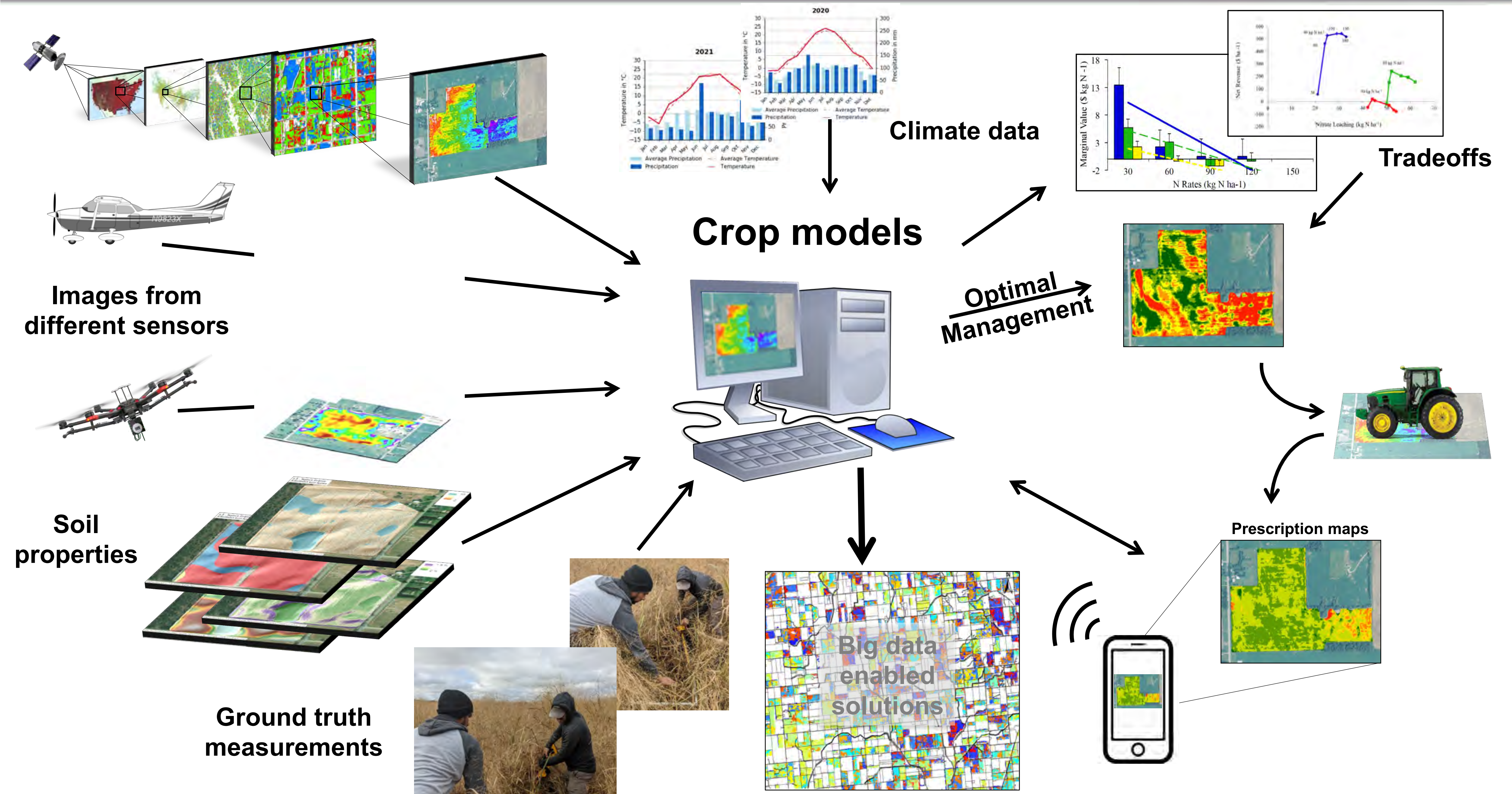
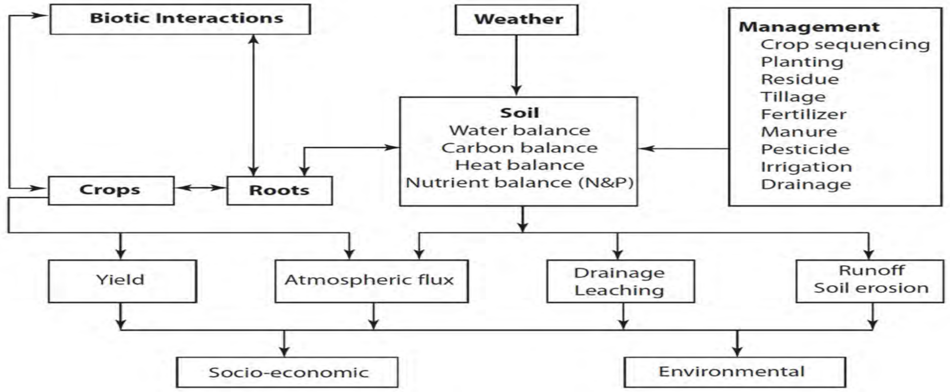
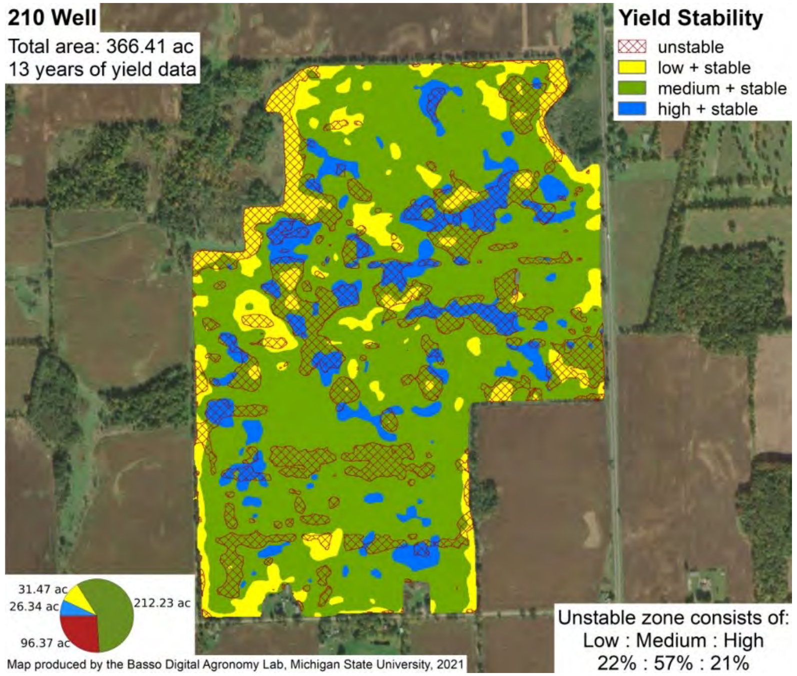


Procedure to design prescription maps

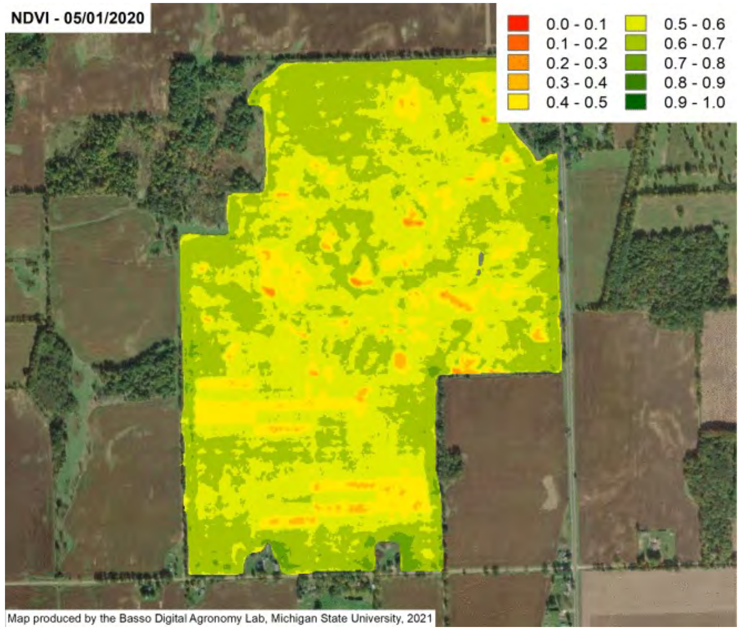
SALUS process-based model

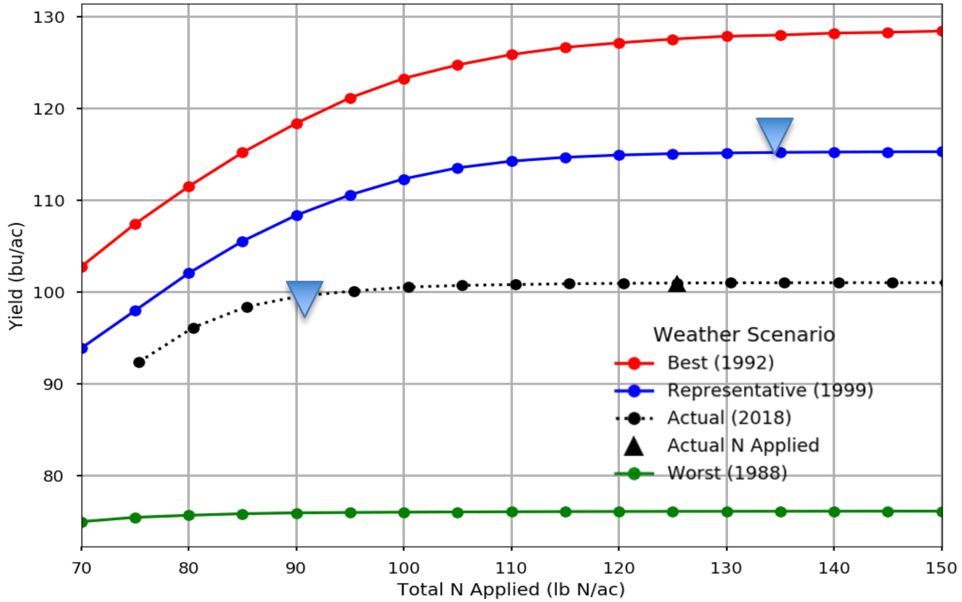


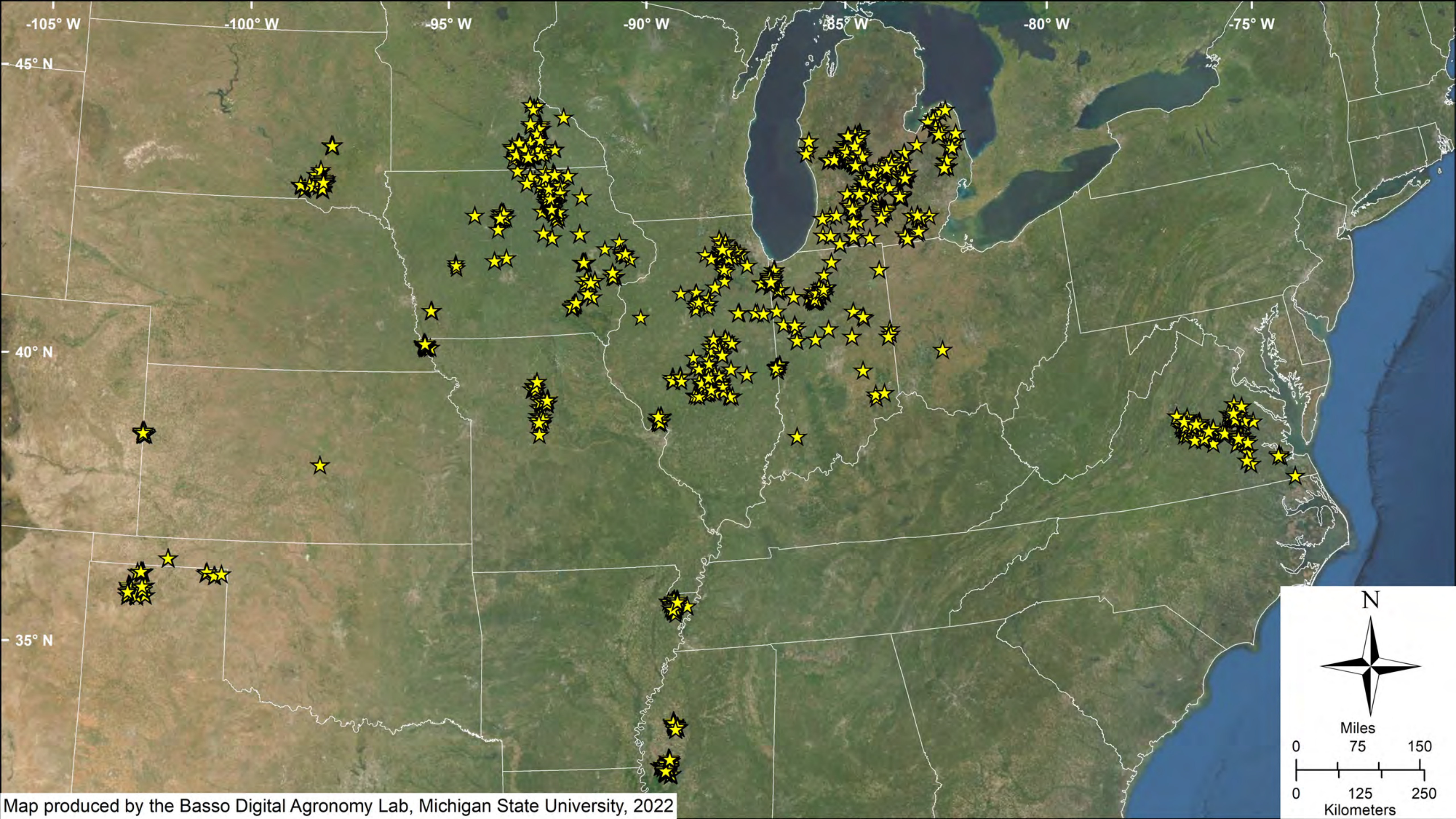
Strategic



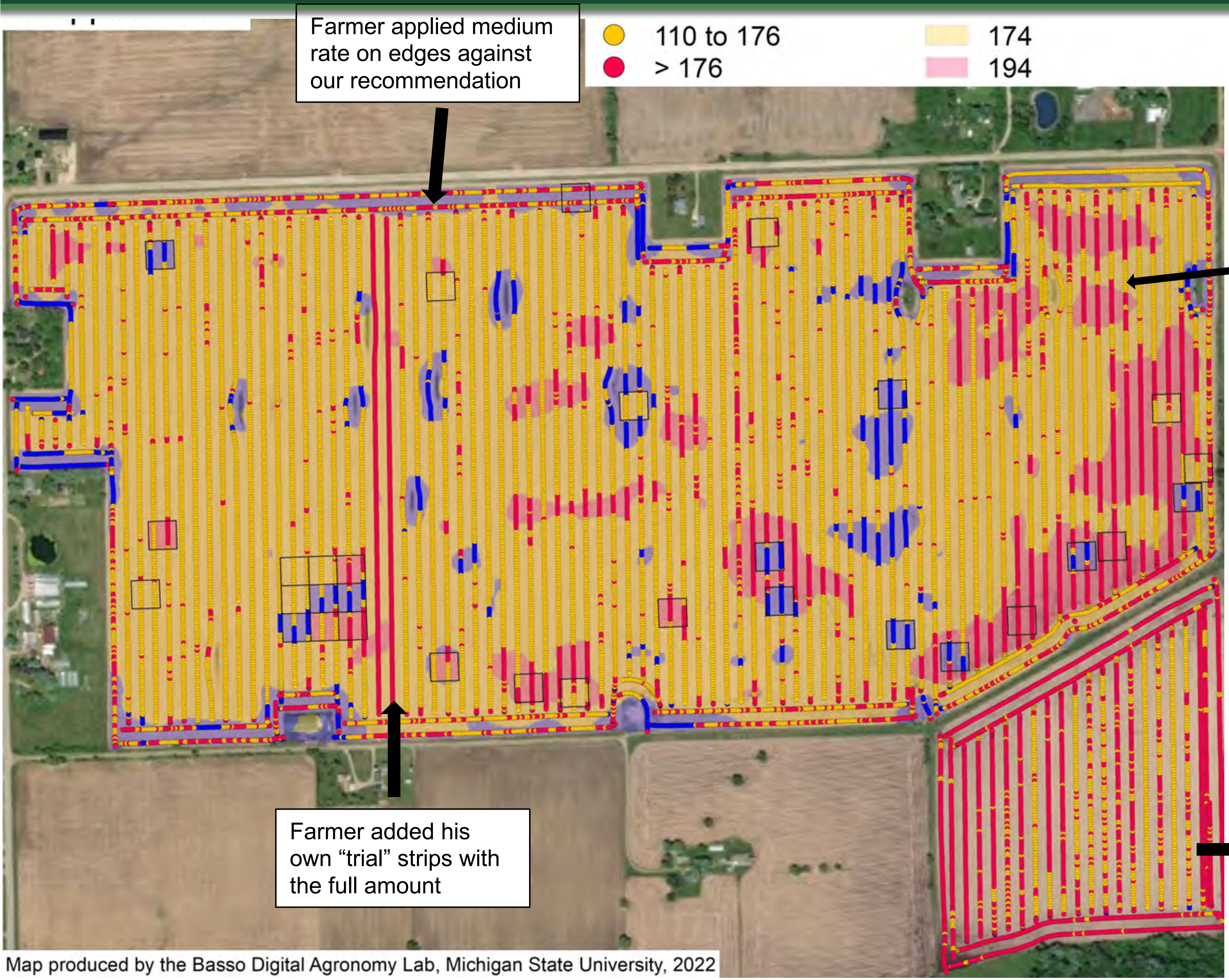
Tactical

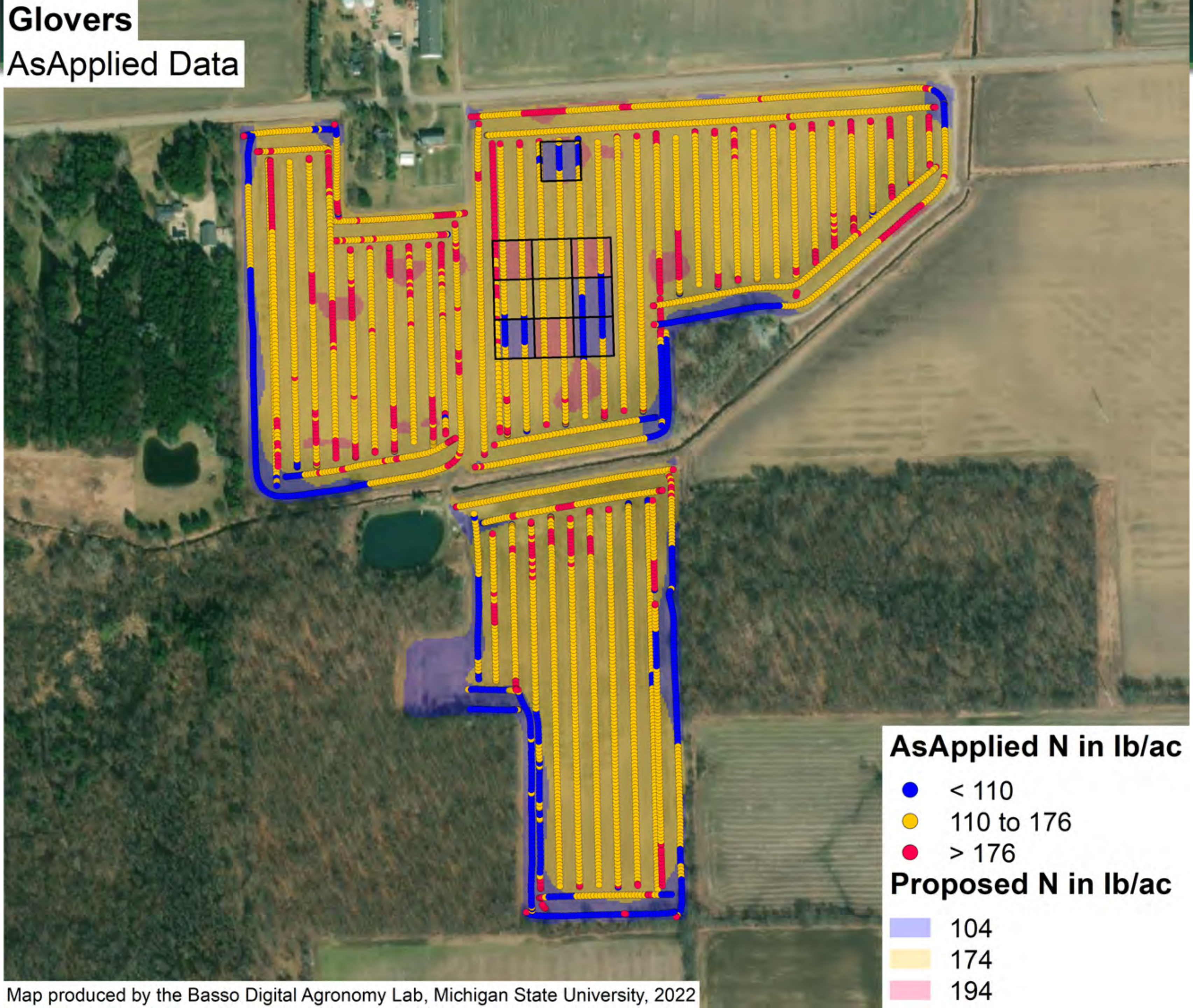





-105° W
-100° W
-95° W
-90° W
-85° W
-80° W
-75° W
45° N
40° N
35° N
N
Miles
0
75
150
0
125
250
Kilometers
Map produced by the Basso Digital Agronomy Lab, Michigan State University, 2022

"As applied N fertilizer map"





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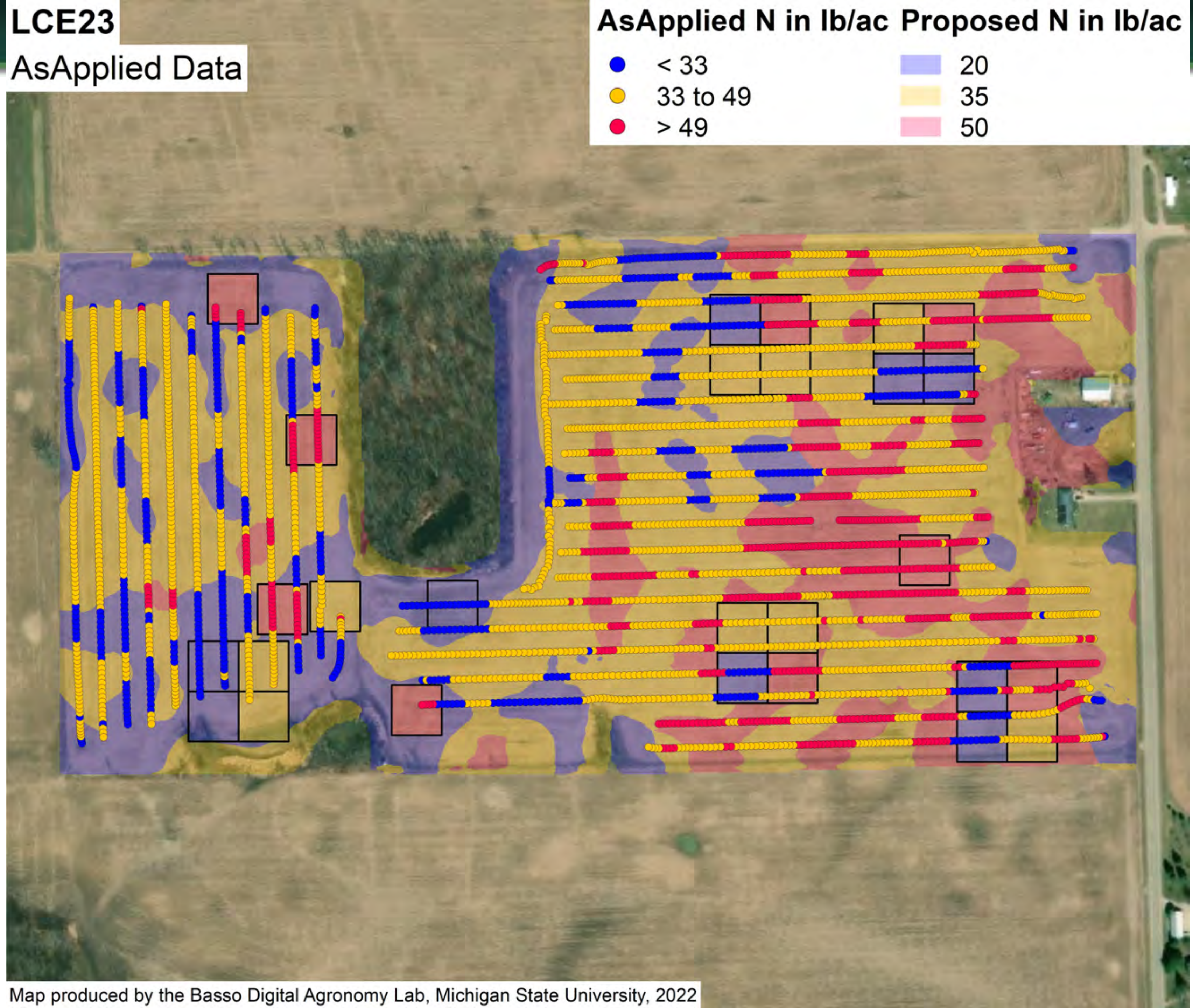
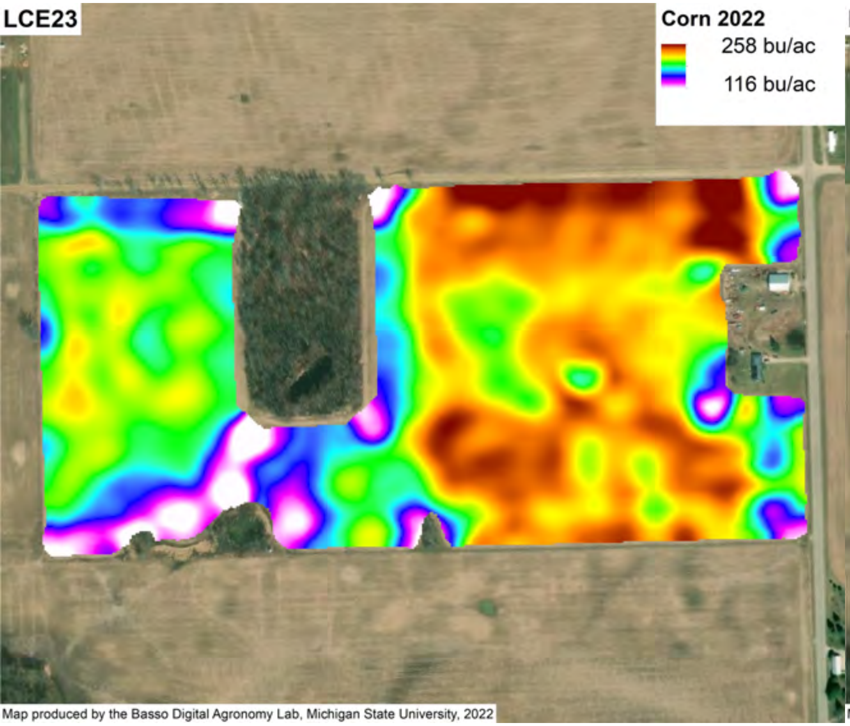
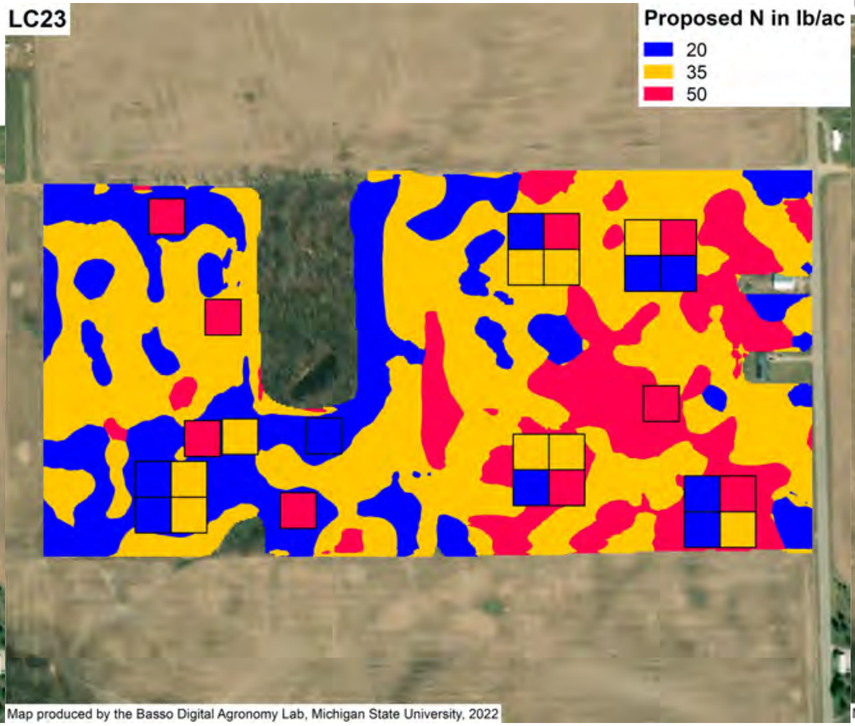
"As applied N fertilizer map"

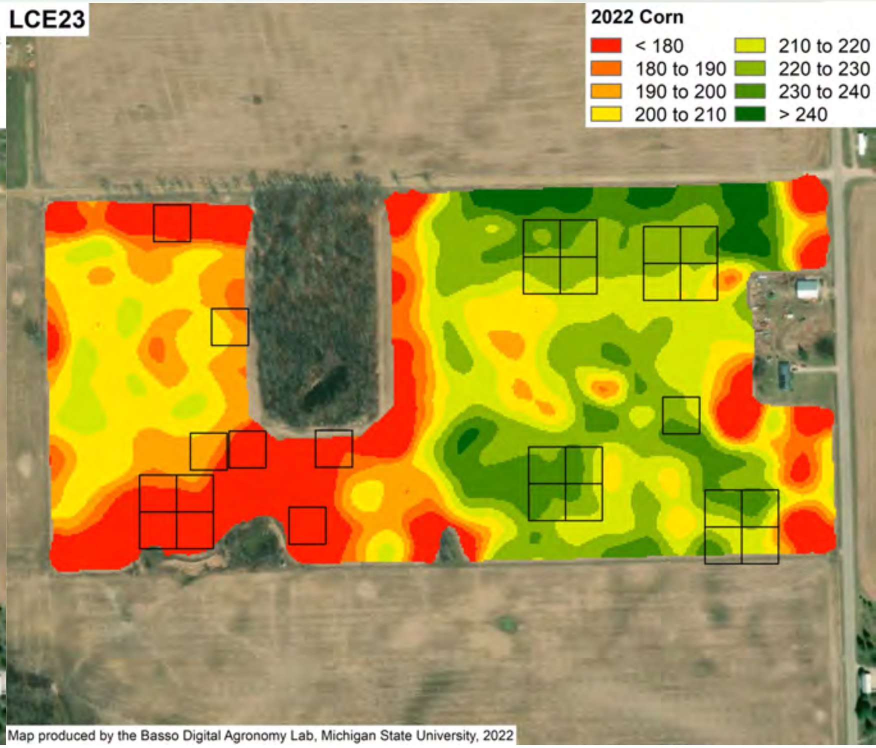


”As applied N fertilizer map”

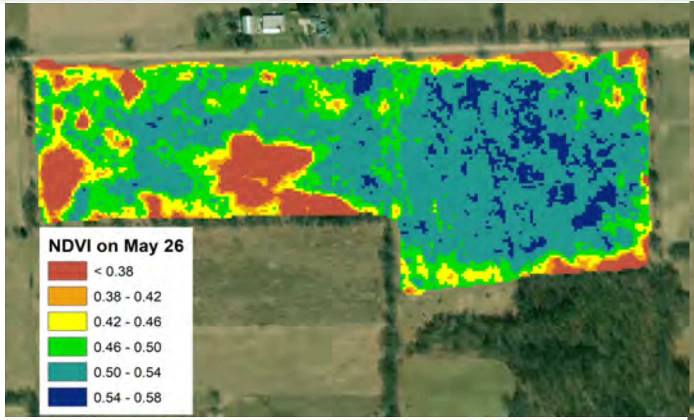
2022 corn yield in different categories with the proposed Rx boxes

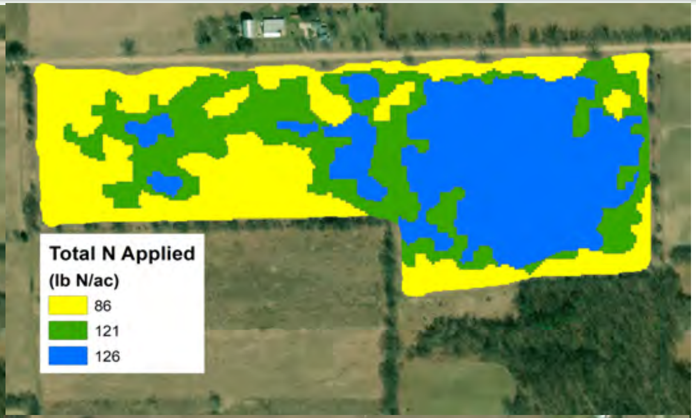


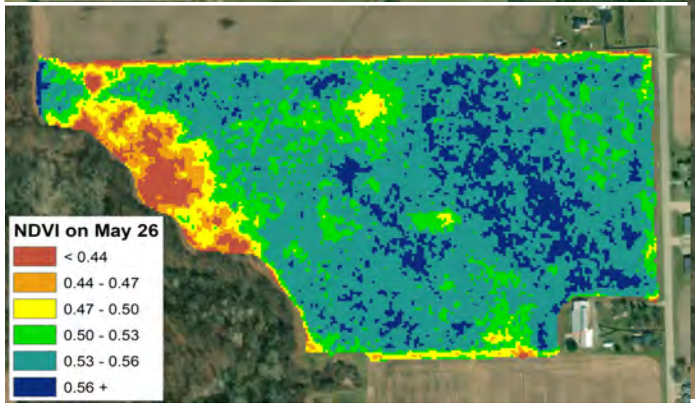


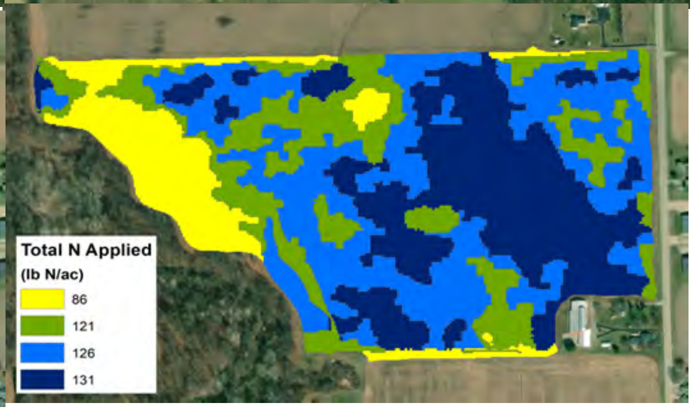


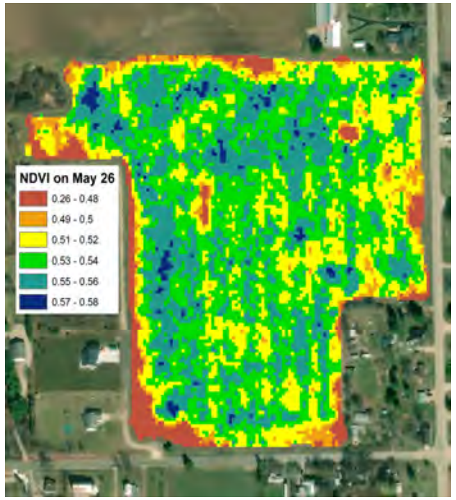
Prescription maps of variable rate N fertilizer

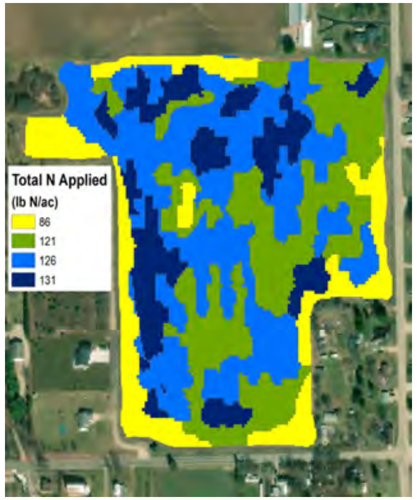


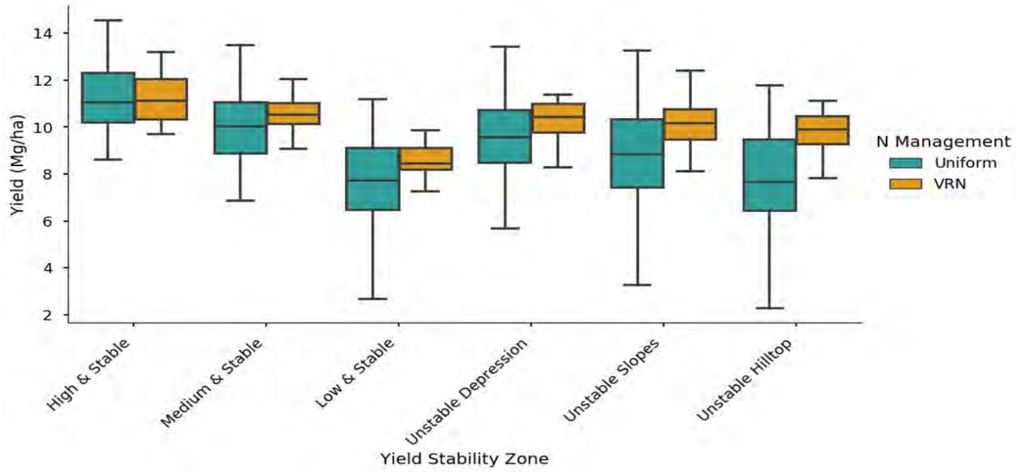


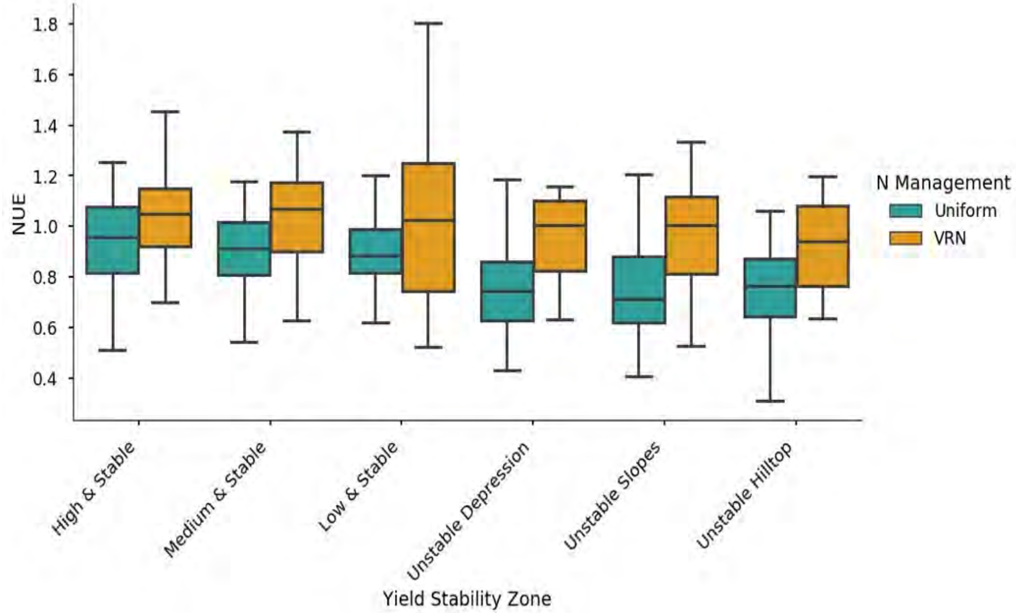




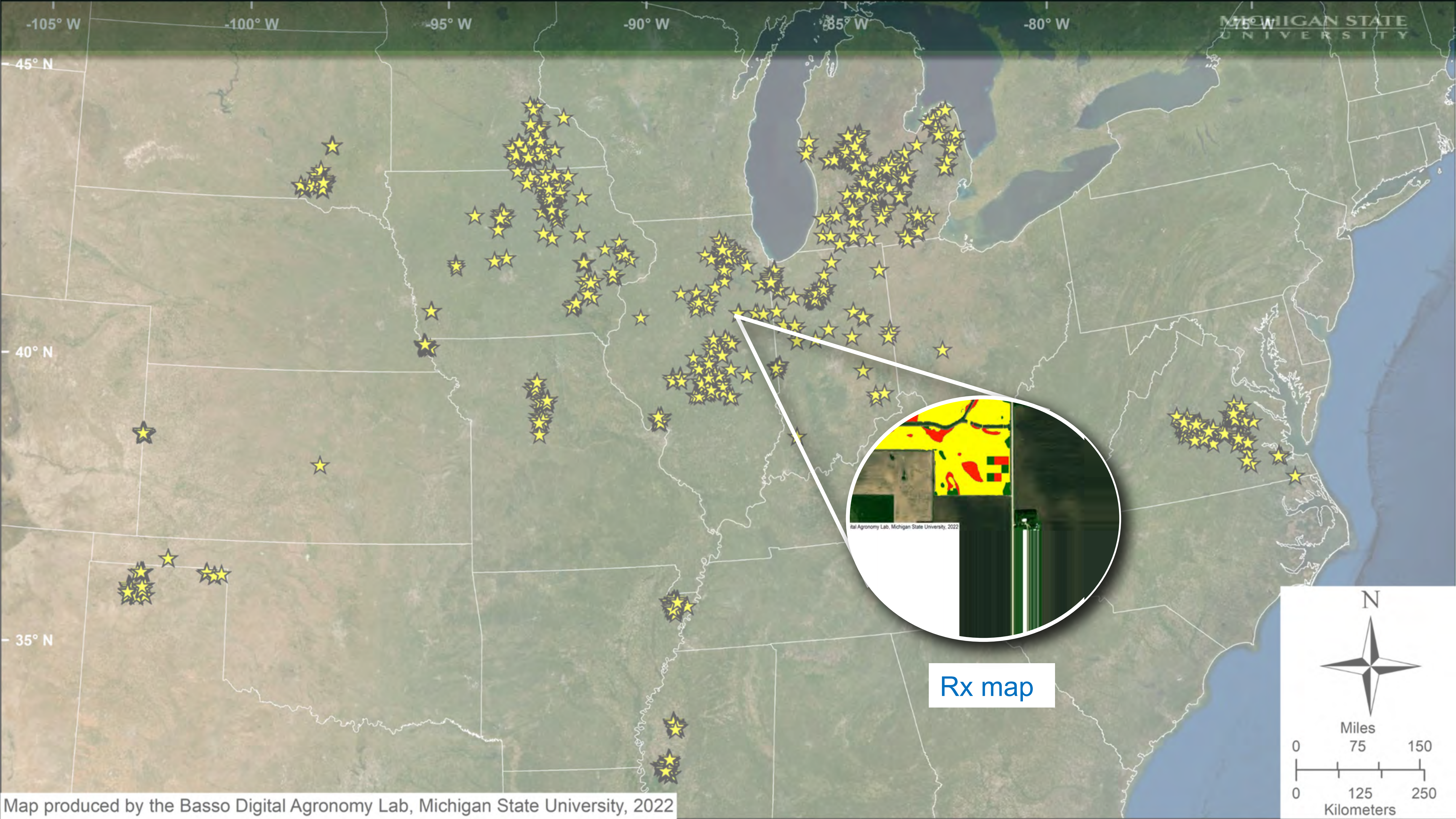








Yield and NUE in Uniform and Variable Rate N at field scale (67 fields)


-105° W
-100° W
-95° W
-90° W
-85° W
-80° W
-75° W
45° N
40° N
35° N
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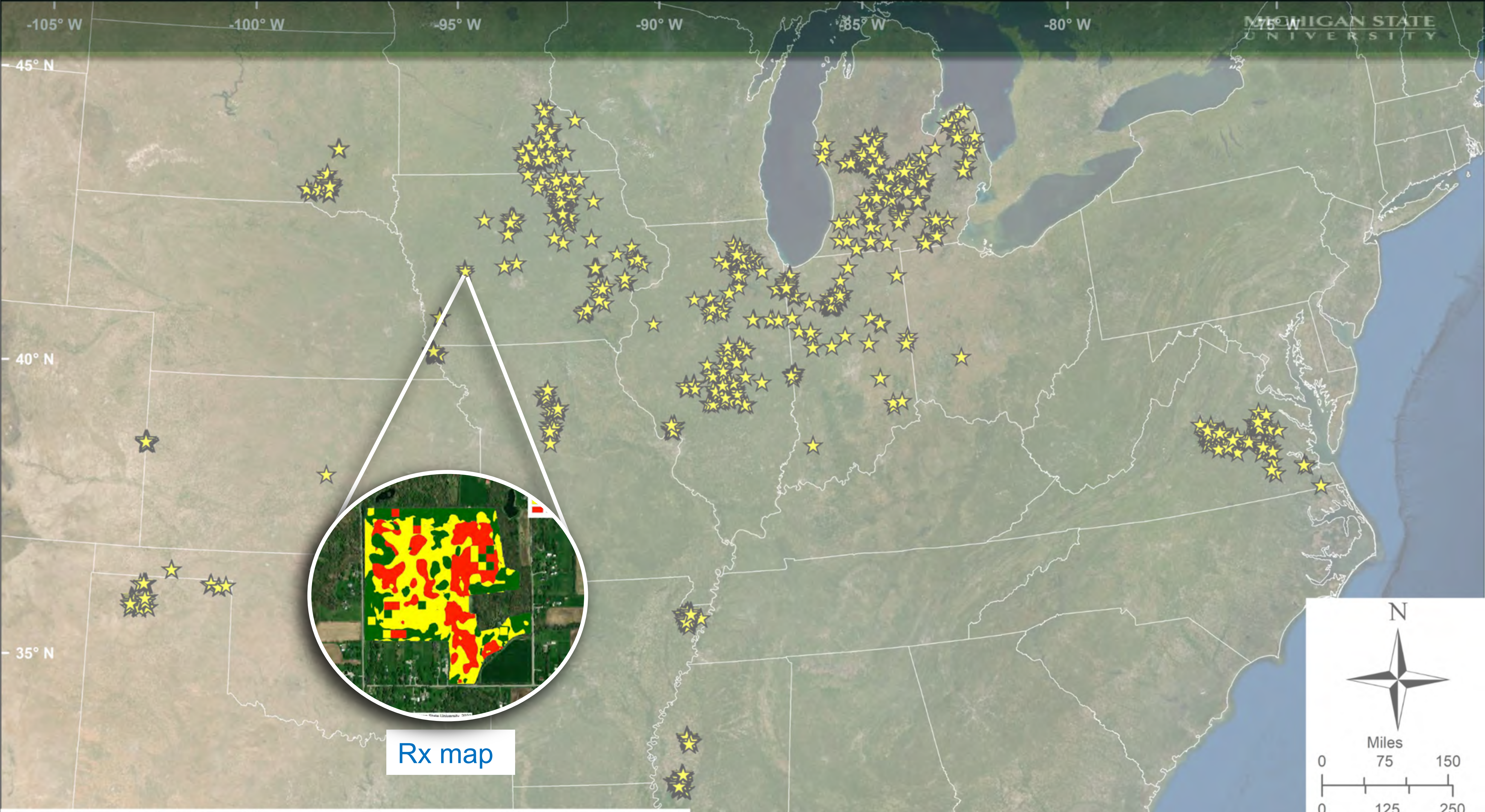
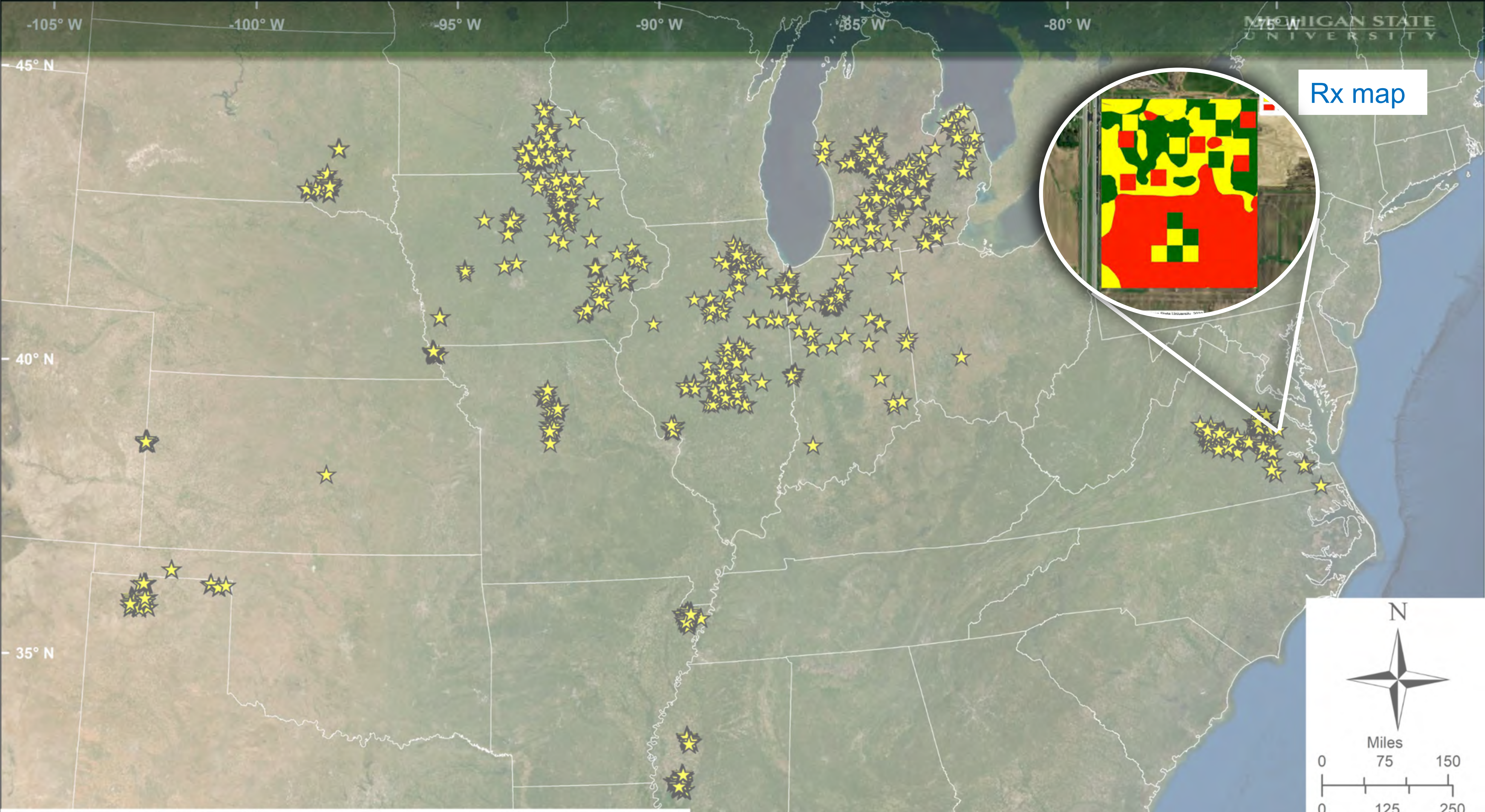
Rx map
N
Miles
0 75 150
0 125 250
Kilometers
Map produced by the Basso Digital Agronomy Lab, Michigan State University, 2022

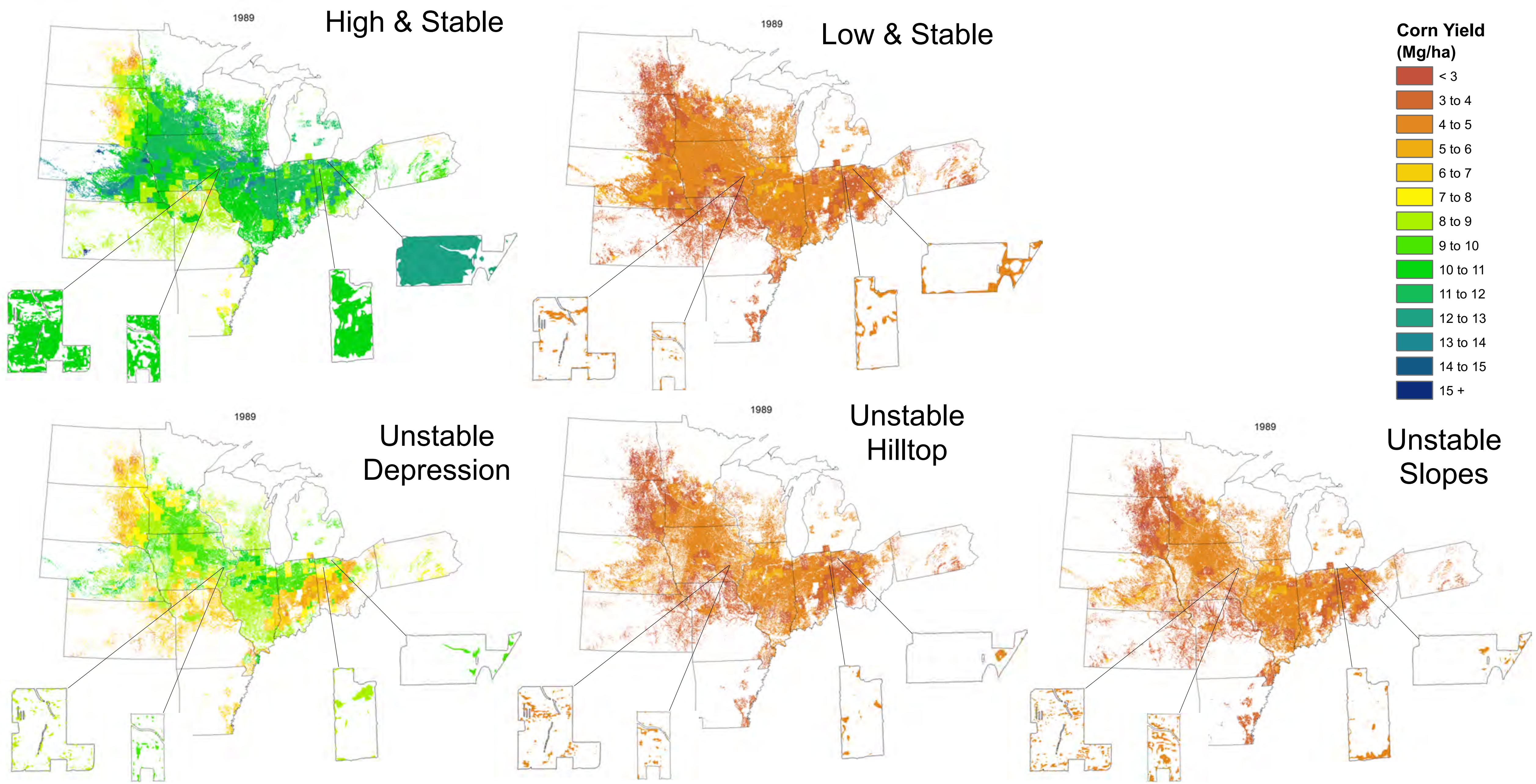


Map produced by the Basso Digital Agronomy Lab, Michigan State University, 2022



Map produced by the Basso Digital Agronomy Lab, Michigan State University, 2022

Modeling crop yield at subfield scale



Modeling Farmers' profitability

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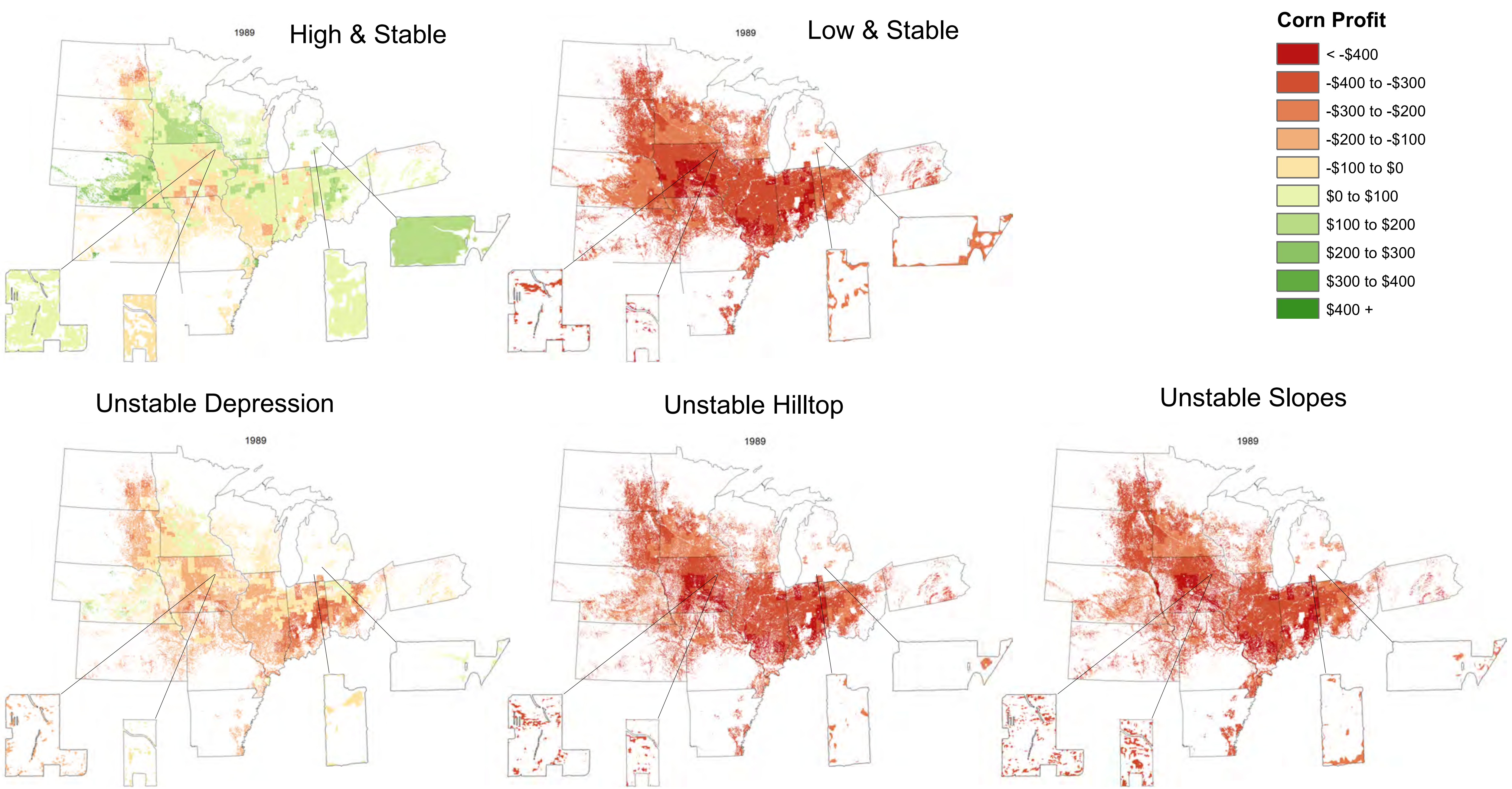
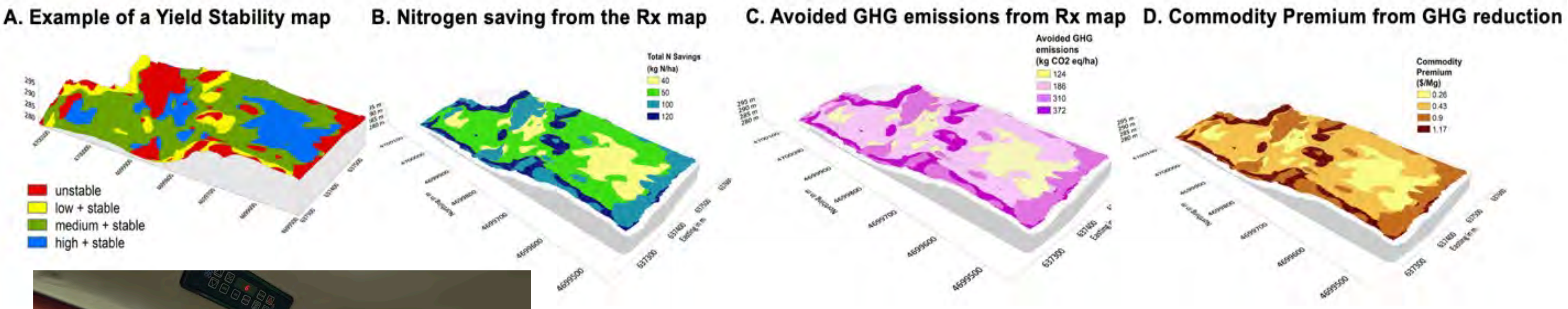
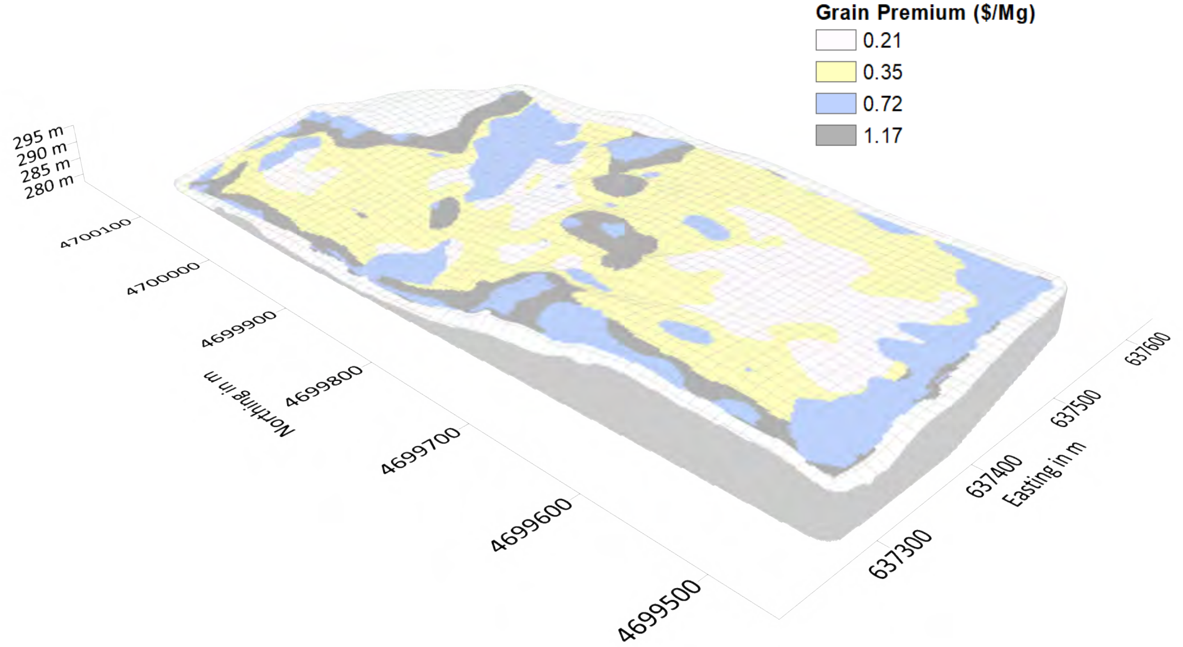


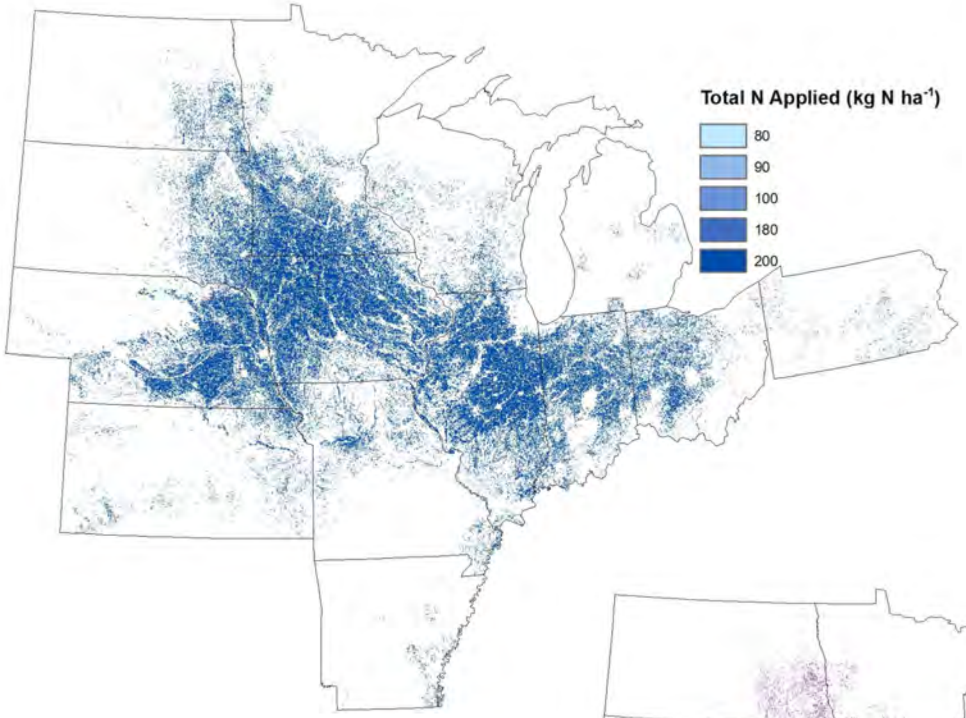
Avoided GHG emissions

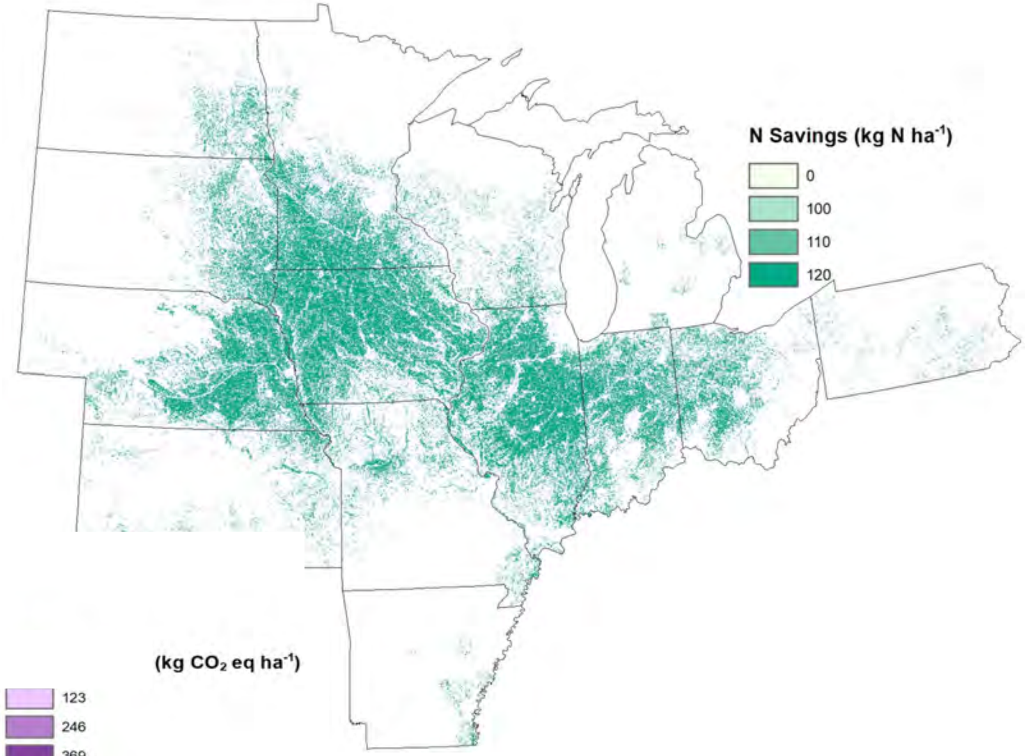


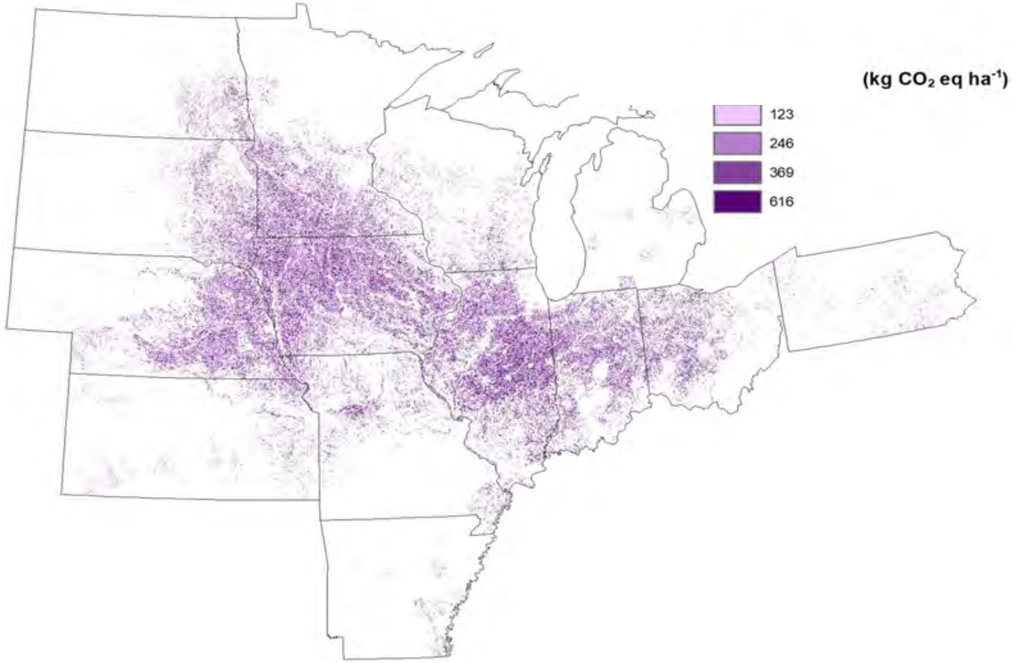


Carbon credits kg/ha CO2e avoided emissions

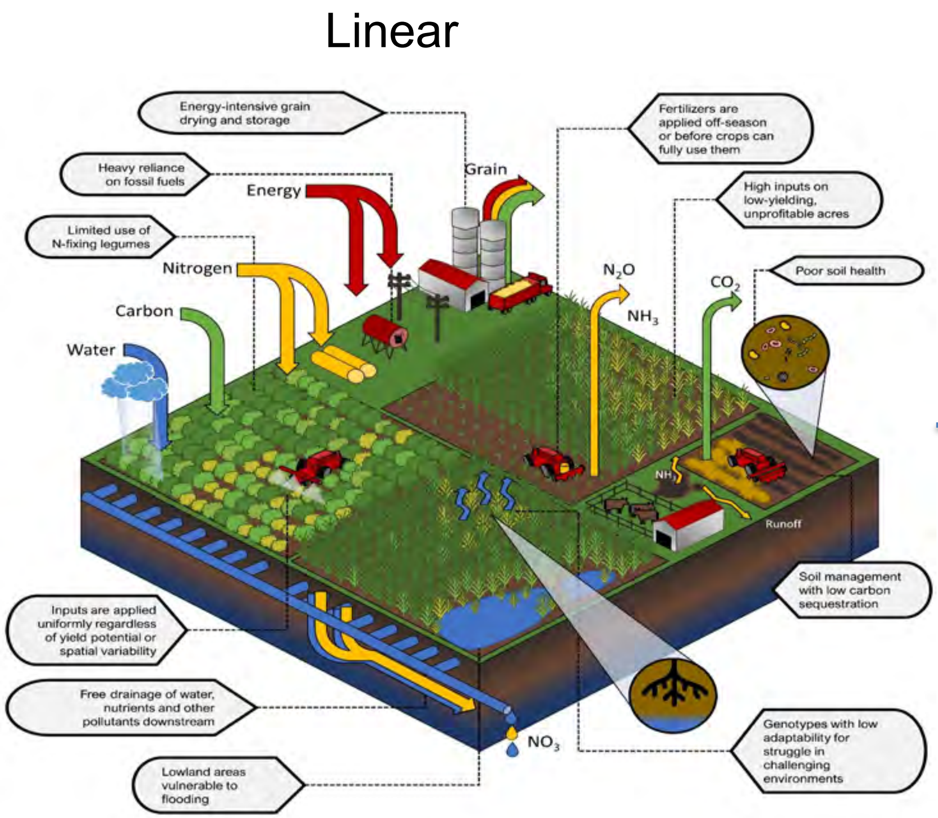
Modeling Avoided Emissions

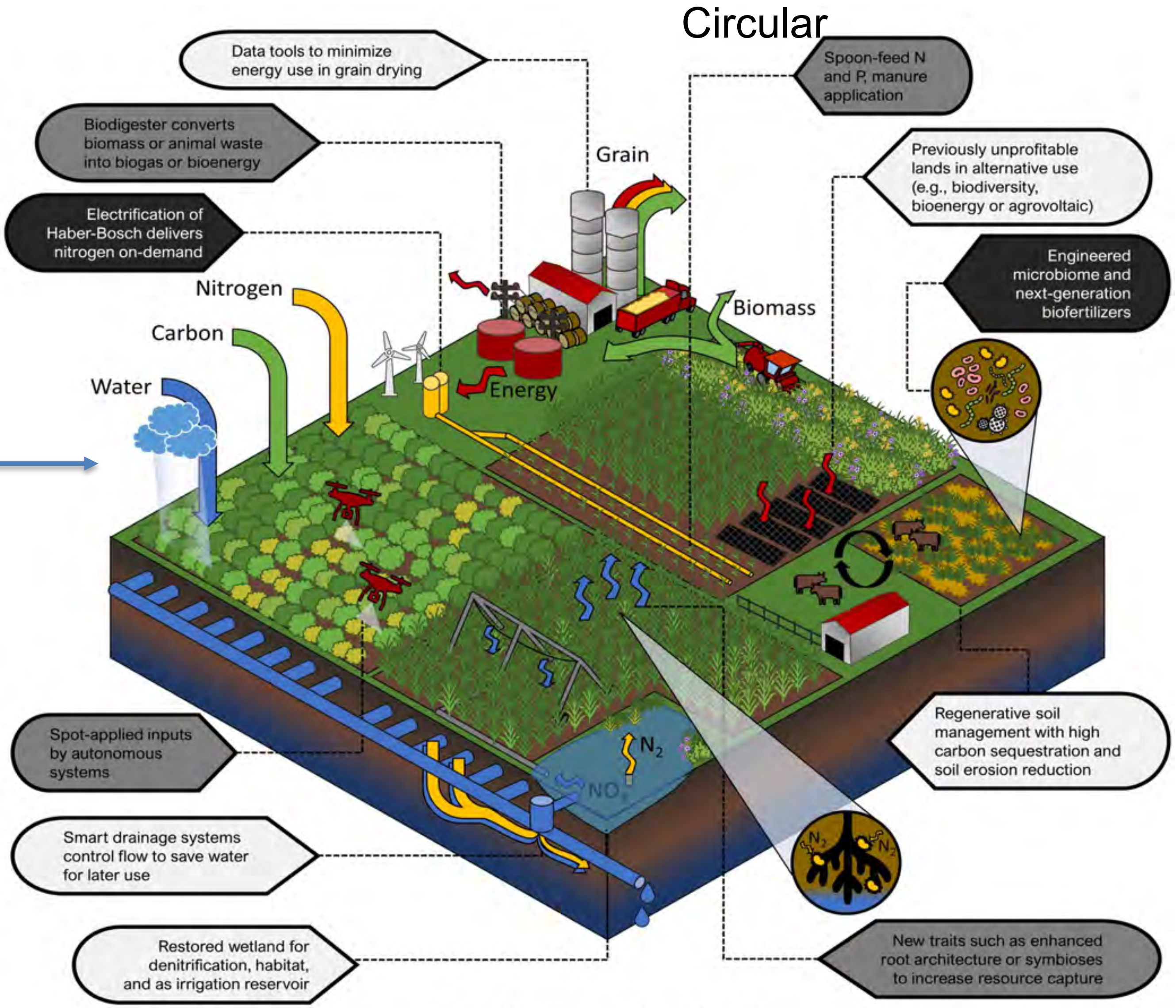




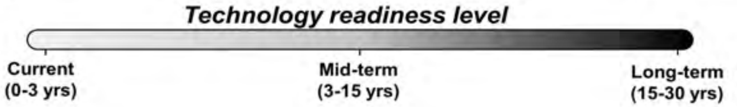


From Linear to Circular Systems





Agriculture can be -70% net negative by 2030



White: current 0 3 yrs
Gray: mid term 3 15 yrs
Black: long term 15 30 yrs

Basso, et al 2021 Ag Syst

Northup, Basso, Wang, Morgan and Benfey et al., 2021, PNAS

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