DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

EXCHANGE: EXpanding the Conversion of HAbitat in the Northern Great Plains Ecosystem

April 4, 2023

Data Modeling and Analysis Technology

Daren D. Redfearn

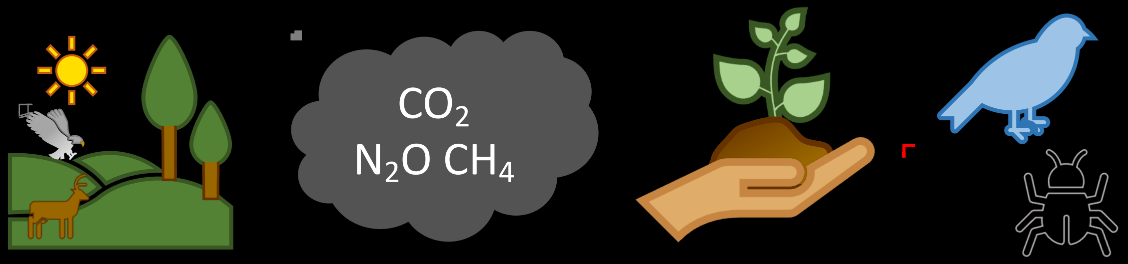
University of Nebraska, Lincoln

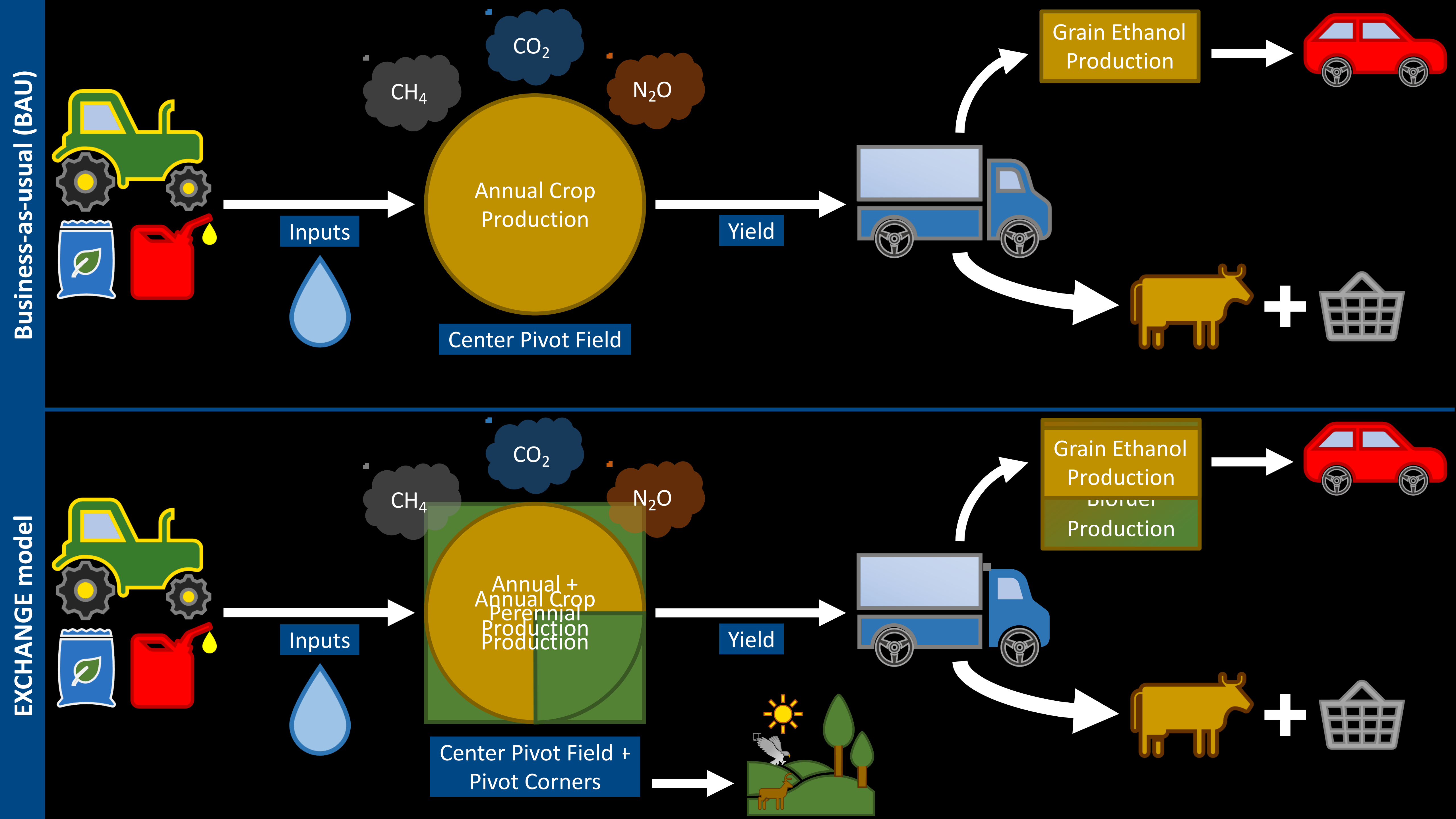
Project Overview

- Quantification of ecosystem services by targeted deployment of switchgrass and other perennial bioenergy grasses into irrigated annual crop landscapes in central and western Nebraska using a transdisciplinary approach to design biodiverse farming systems comparing business-as-usual (BAU) with perennial bioenergy grasses.

↑ 20% soil organic C

↓ 20% nutrient loss




Business-as-usual (BAU)
CO_2
CH_4
N_2O
Annual Crop Production
Inputs
Yield
Center Pivot Field
Grain Ethanol Production
EXCHANGE model
CO_2
CH_4
N_2O
Annual + Perennial Production
Annual Crop Production
Inputs
Yield
Center Pivot Field + Pivot Corners
Grain Ethanol Production
Production

Technical Approach: Key metrics/Modeling

EXCHANGE

Ecosystem services

- Soils sampled to evaluate soil organic C (SOC) stocks, soil health and soil microbial community composition.
- Greenhouse gas (GHG) emissions (carbon dioxide, CO_2; nitrous oxide, N_2O; methane, CH_4) measured.
- Arthropod communities sampled targeting important ecosystem service metrics.
- Avian utilization of bioenergy.

Regional water use/groundwater

- Changes in water quantity and quality in the Republican River watershed.
- Evapotranspiration (ET) monitoring
- Soil moisture by depth

Metric integration

- Techno-economic analysis (TEA)
- Ecosystem service valuation (ESV)
- Life cycle assessment (LCA)

Technical Approach: Budget Periods 1, 2, 3

EXCHANGE

Budget period 1

Establish field studies, initiate collection of field data, model input and initial verification

Perennial bioenergy grass establishment

Budget period 2

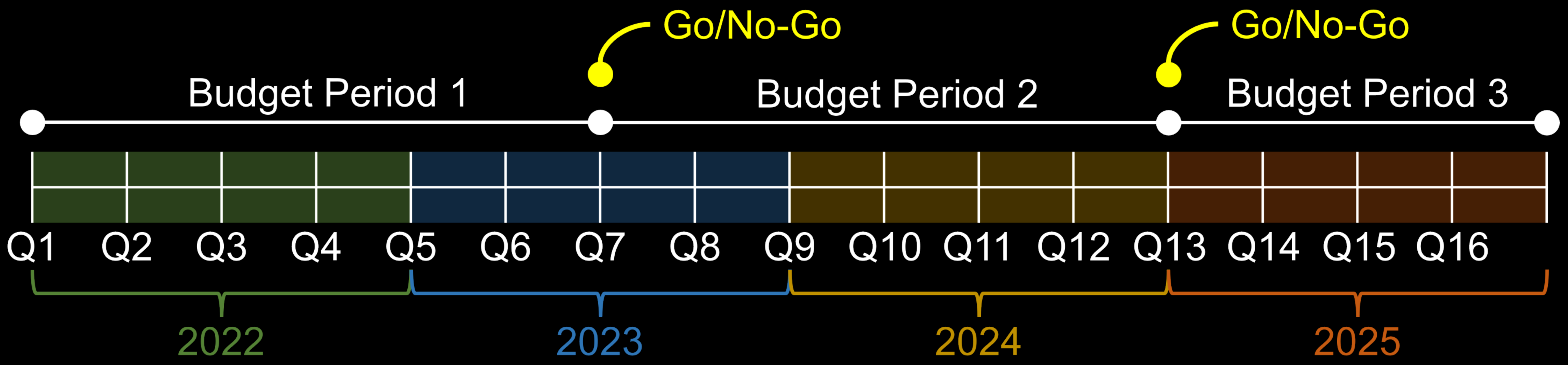
Feedstock production management, complete data collection, ground water modeling, TEA/ESV/LCA

Budget period 3

Final data analysis, modeling, and outreach

Perennial bioenergy grass establishment

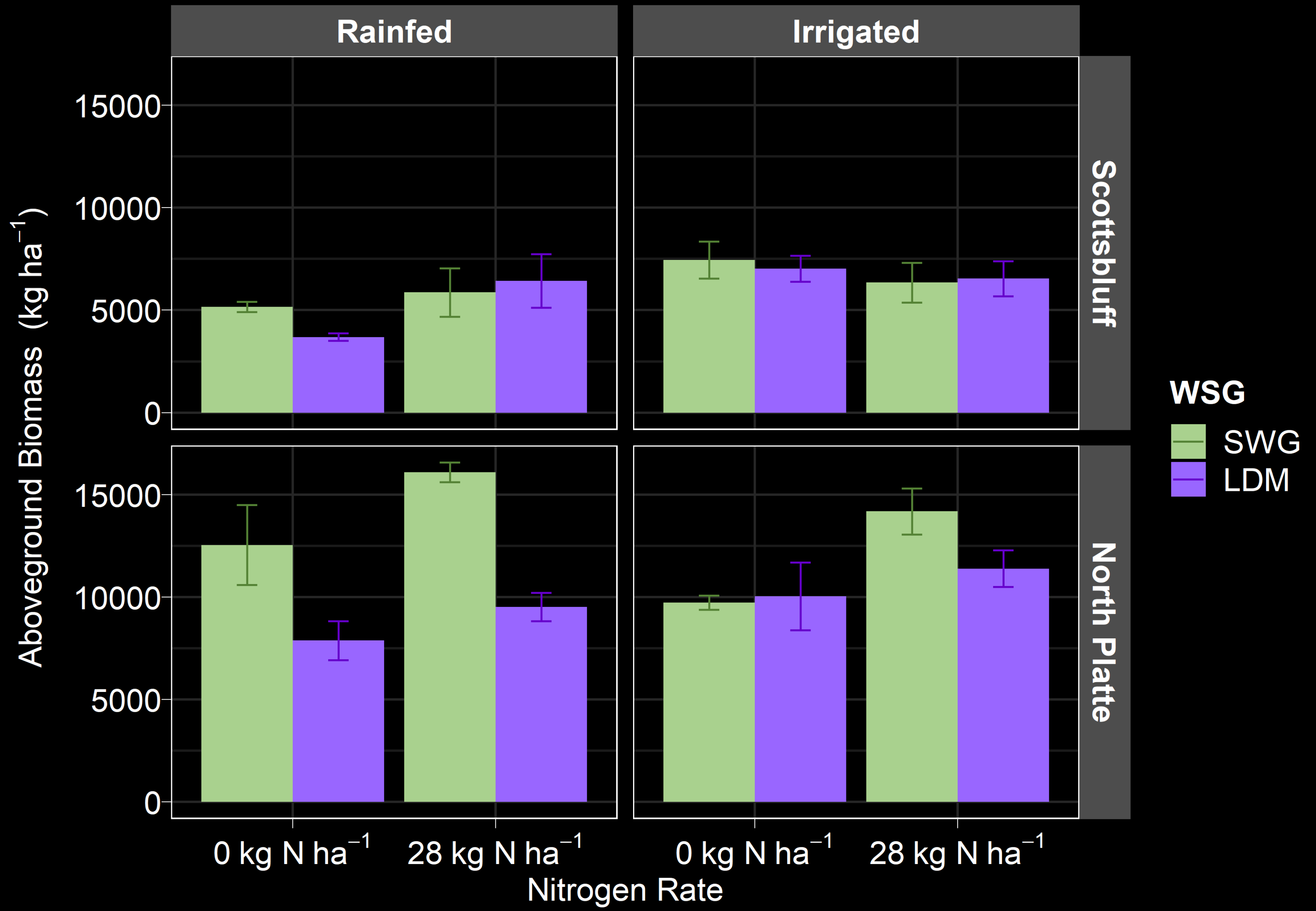
Technical Approach: Budget Periods 1, 2, 3



Progress and Outcomes

- Task 1. **Perennial Bioenergy Grass Production**
  - Task initiated; preliminary data will be presented.
- Task 2. **Ecosystem Service Measurement**
  - Task initiated; preliminary data will be presented.
- Task 3. **Regional Water Use and Groundwater Modeling**
  - Task initiated.
- Task 4. **Techno-economic Analysis/Life Cycle Assessment and Ecosystem Services Valuation**

Perennial Bioenergy Grass Production



Soil Organic Carbon and GHG Emissions

EXCHANGE

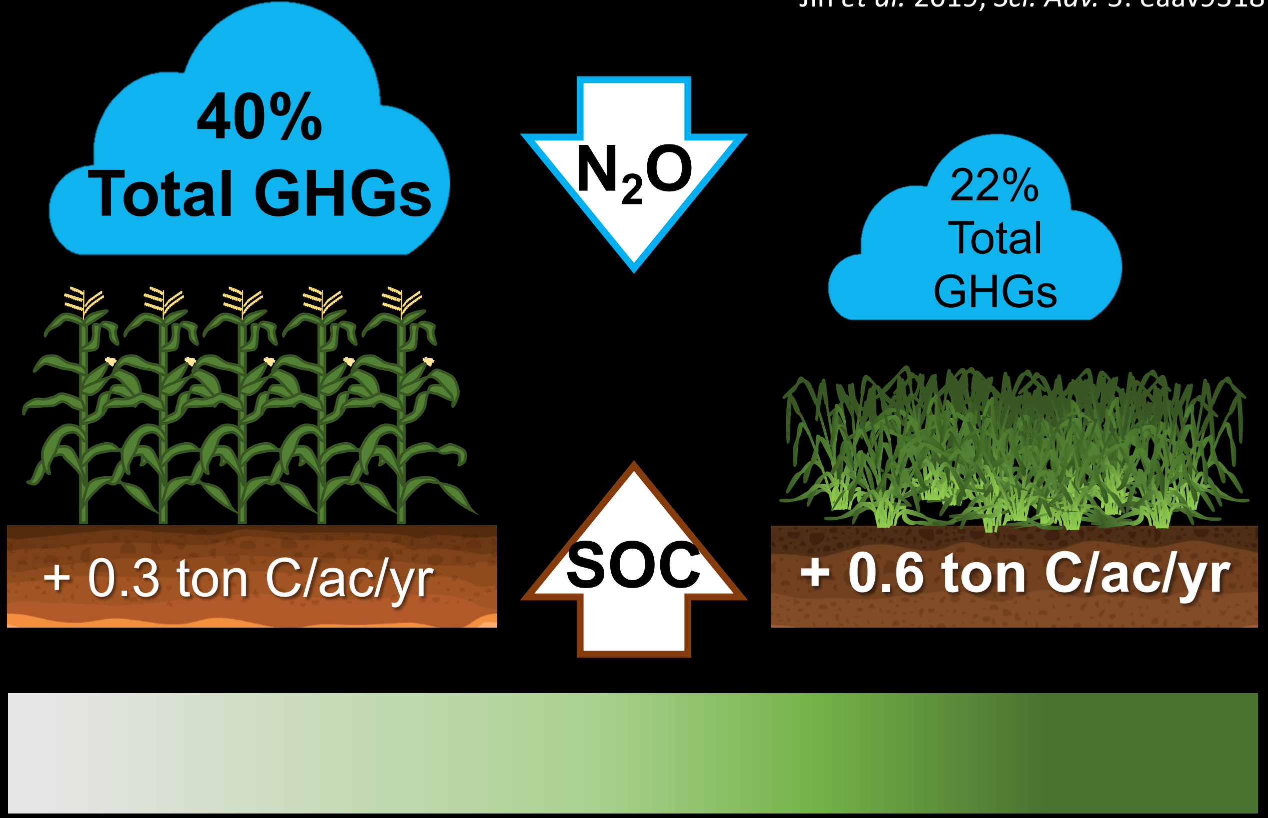
- **Soil C/Biology/Health**
  - Plot studies: initial, final
  - On-farm: CRP vs row-crop
  - Standard soil-test analyses
  - Soil microbial communities
  - Soil C changes over time

- **Soil GHGs**
  - Plot studies only
  - Winter: every 4-6 wks.
  - Spr./Fall: every 2-3 wks.
  - Growing season: 10-14 d

Benefits of Perennial Grasses

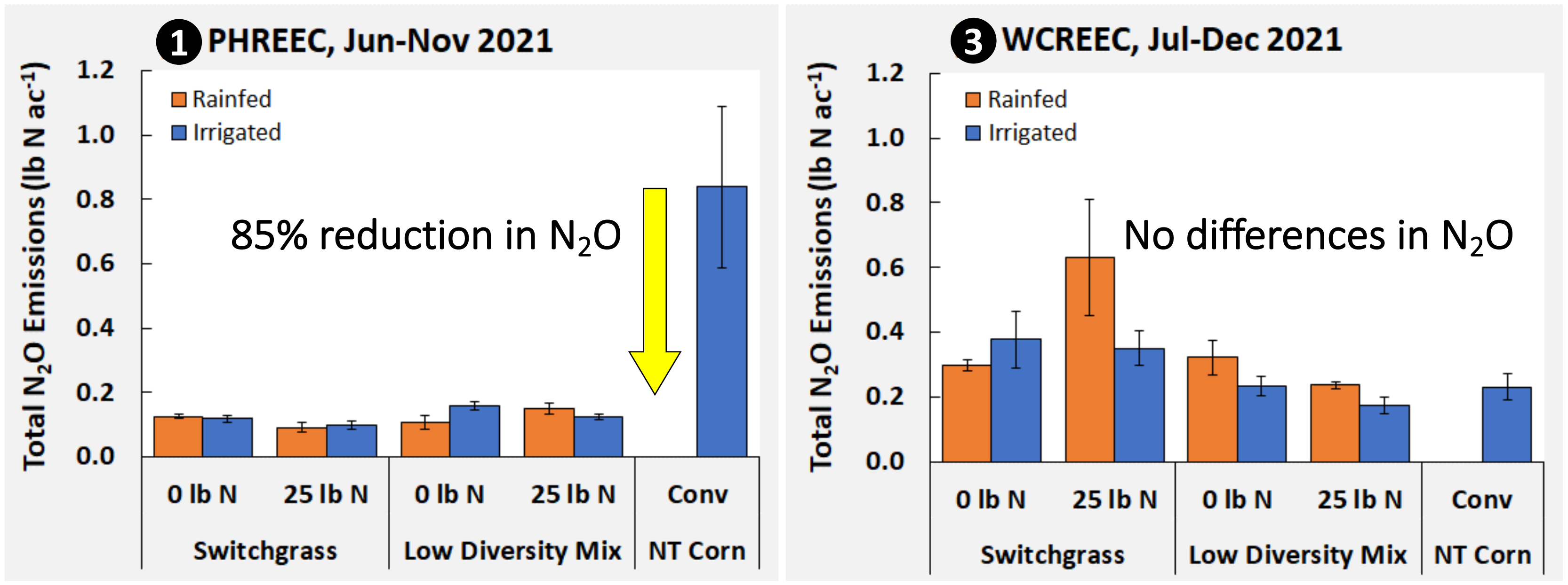
EXCHANGE

Jin *et al.* 2019, *Sci. Adv.* 5: eaav9318



Higher input costs + Lower corn prices = Opportunities for returning perennials to marginally productive croplands

Preliminary: 2021 Soil GHG Emissions

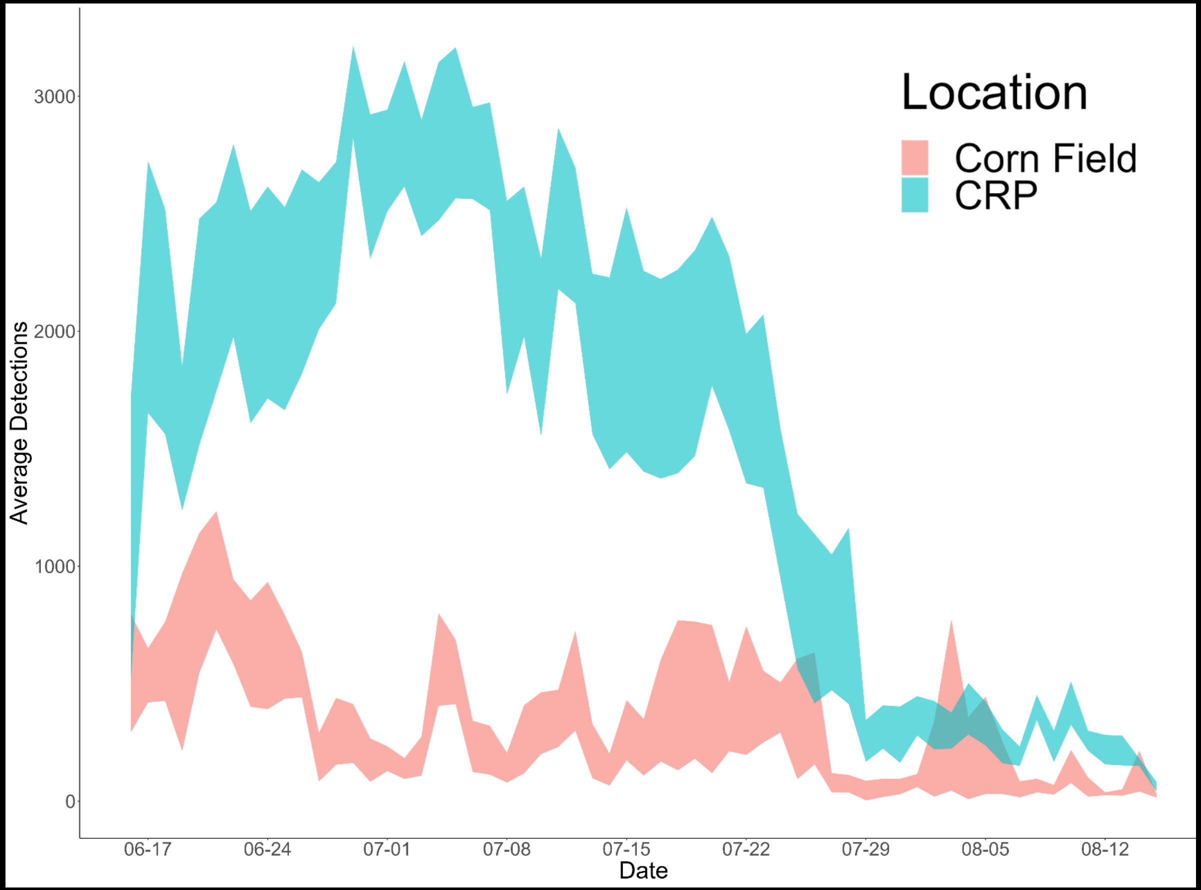


1. Panhandle Research, Education, and Extension Center (PHREEC)
2. High Plains Agricultural Laboratory (HPAL)
3. West Central Research, Education, and Extension Center (WCREEC)

- Sample timing can drive site-specific differences
- Early N_2O flush captured at 1 but not 3
- Biological activity (CO_2) ↑ 30-60% with irrigation
- Soil CH_4 emissions negligible

2021 Avian & Wildlife Monitoring

Greater avian acoustic activity in CRP fields



Top 3 Bird Species Detected

Corn Field

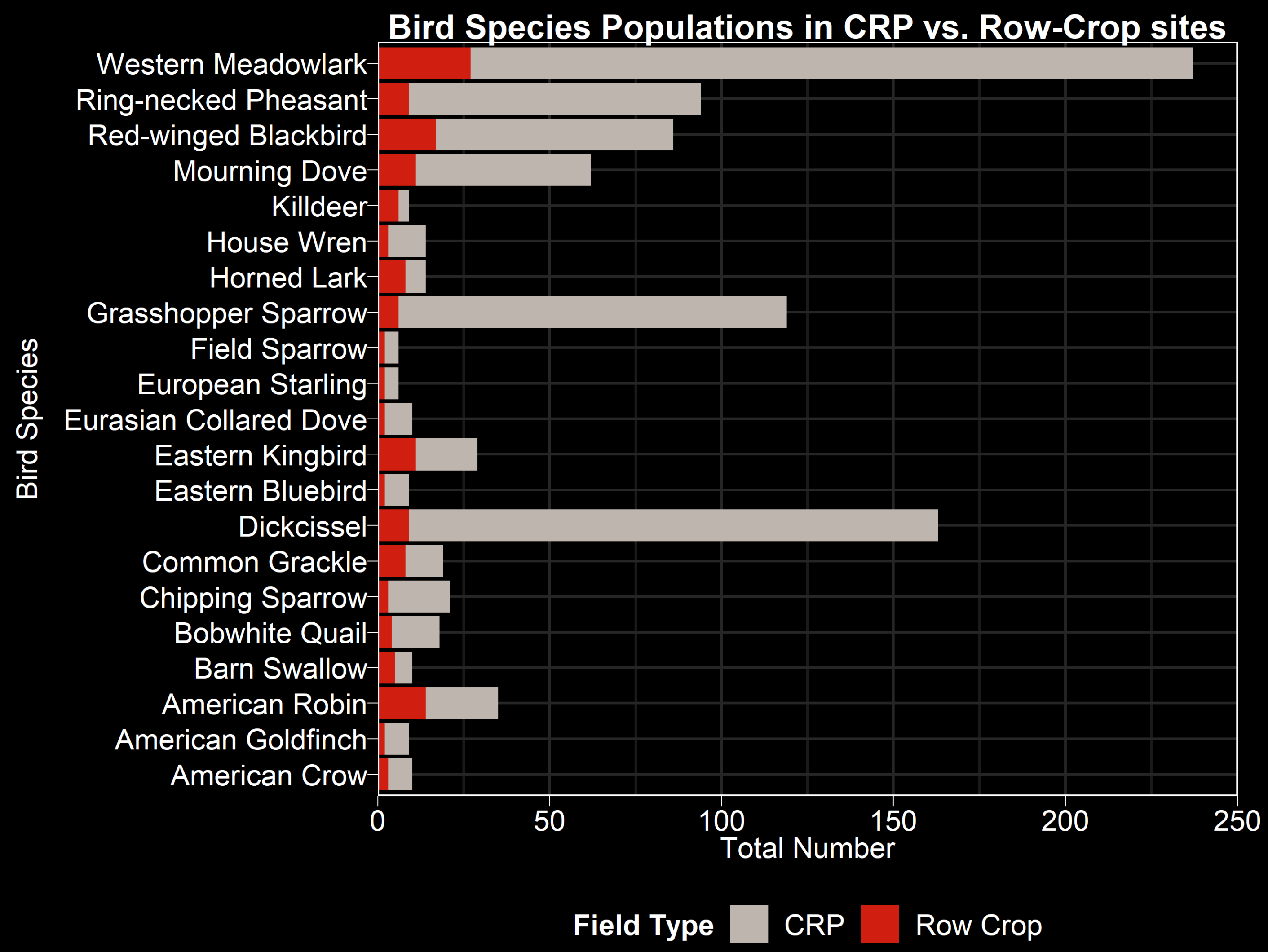
Common Name	Total Detections
Horned Lark	28,180
Dickcissel	22,410
American Robin	12,889

CRP

Common Name	Total Detections
Dickcissel	368,399
Grasshopper Sparrow	54,945
Eastern Kingbird	10,991

Several other wildlife species detected

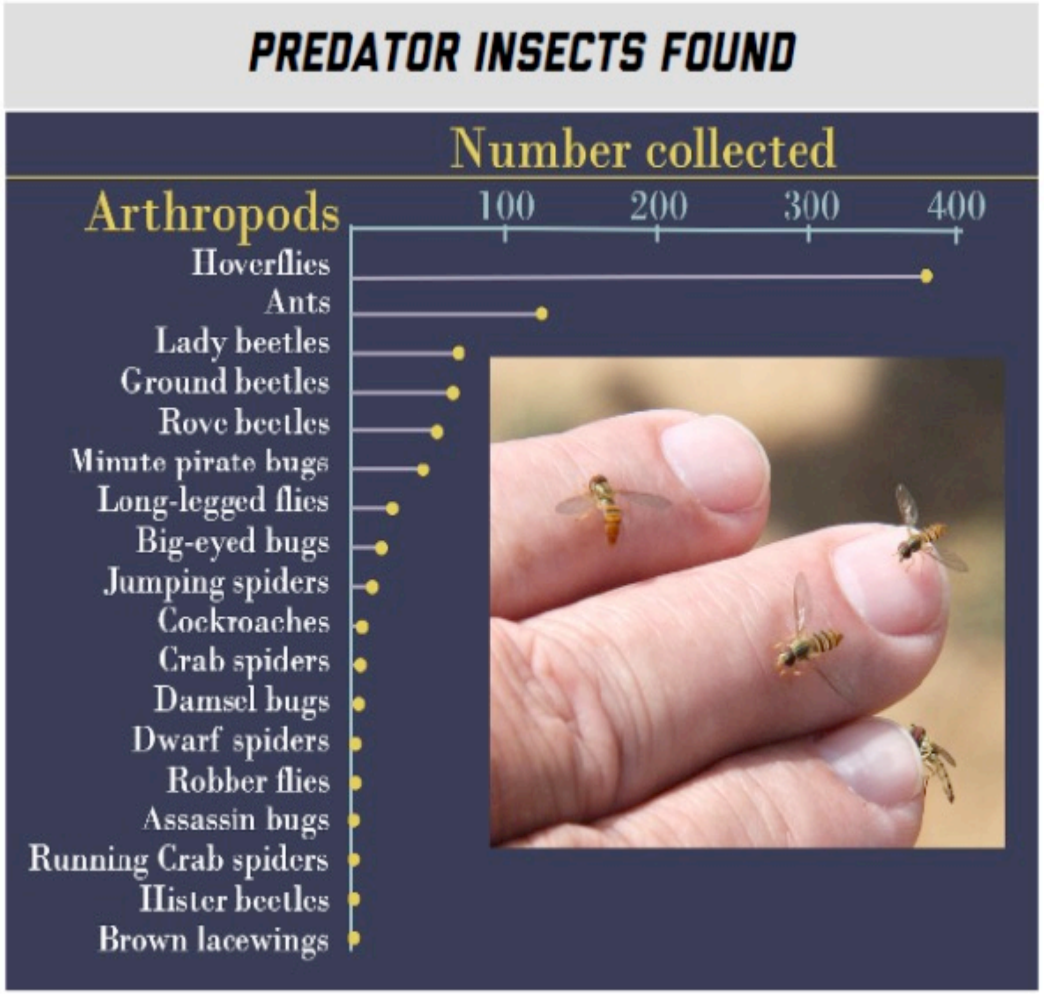
2022 Avian Monitoring



- **Fifty-four avian species were identified** across all sites.
- **Avian biodiversity was greater in grassland than cropland** except for killdeer (66%) and horned larks (28%).
- Most common avian species were
  - dickcissel (15.4%), grasshopper sparrow (11.3%), pheasant (9.4%), western meadowlark (22.4%), red-winged blackbird (8.1%).
- Least common avian species were
  - burrowing owl (0.1%), common yellow throat (0.1%), Cedar waxwing (0.1%), and LeConte sparrow (0.1%).

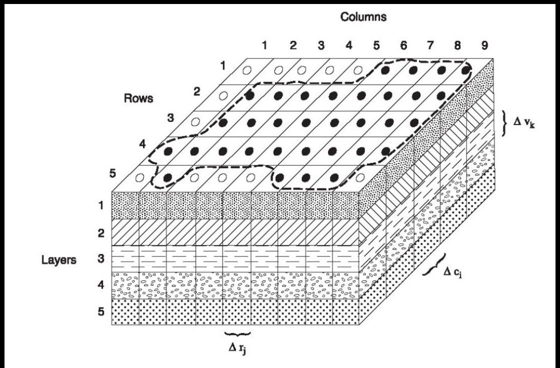
2022 Arthropod Monitoring

- **More insect pollinators were observed in grassland than cropland** with the greatest numbers in the center of the grasslands.
- **Grasslands supported the greatest biodiversity of pollinator species**, and our most common pollinator was sweat bees, followed by rose chafer beetles and soldier beetles.
- **More predator arthropods were observed in cropland than grassland**
- The most common predatory arthropods caught on sticky cards were hover flies, followed by ants, lady beetles, ground beetles, and rove beetles.
- **Ants were observed with greater frequency in grassland.**
- Pitfall traps collected the highest number of ants, though ground beetles, and spiders were also well represented.

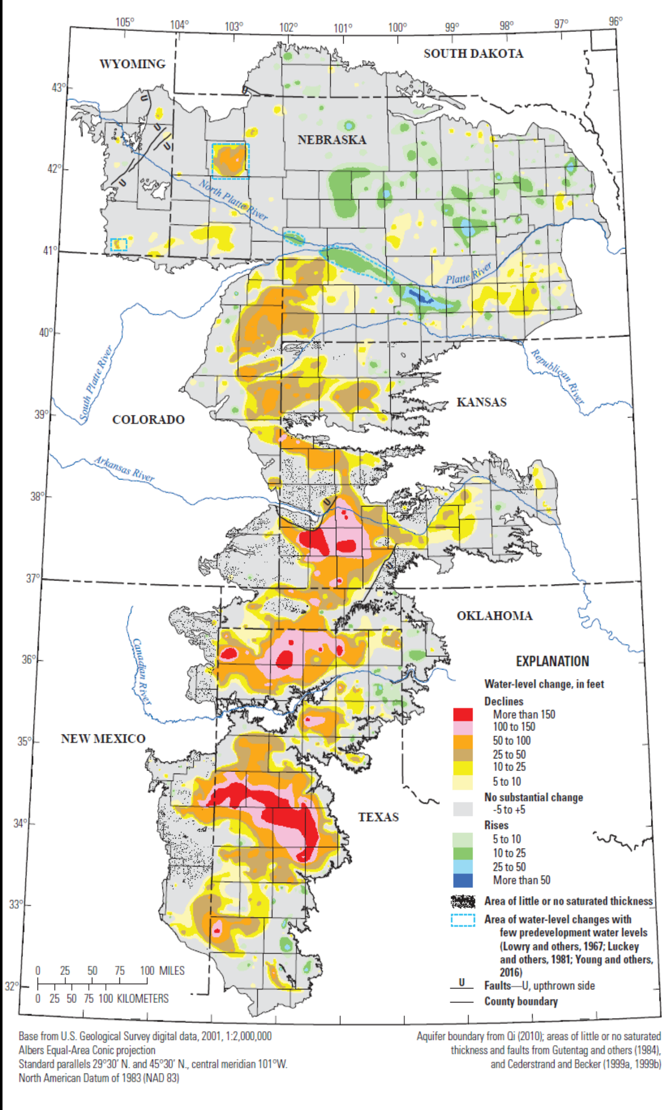


Ground Water Resources

- **EXCHANGE** project driver is concern for long-term sustainability of the Ogallala Aquifer
  - Mining of the groundwater, mainly by irrigation
- Groundwater systems can be modeled to calibrate heads and flows to target values by adjusting parameters
  - Hydraulic conductivity (permeability)
  - Recharge rate
  - U.S. Geological Survey numerical model code MODFLOW



General example of groundwater system discretized in a numerical model (source: USGS)



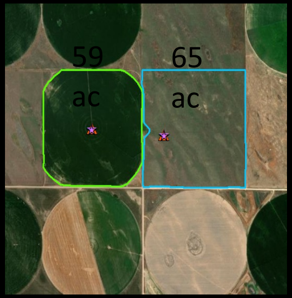
Water-level changes in the High Plains aquifer, predevelopment (about 1950) to 2015 (source: USGS 2017)

Estimation of Evapotranspiration (ET)

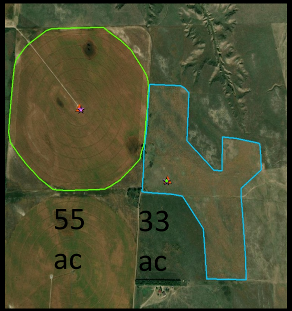
- **Approach**
  - Utilize the METRIC (Mapping of ET at high Resolution with Internalized Calibration)* on non-cloudy days
  - Explore soil moisture-based ET estimation using machine learning (ML)-based modeling for cloudy days
- **Expected Outputs**
  - Spatially resolved (30-m resolution) estimates of actual ET of perennial grass and commodity crop treatments
  - ML-based model for predicting daily soil moisture content and/or ET for perennial grass and commodity crops.

On-site weather stations were installed collecting weather and soil data (moisture & temperature)

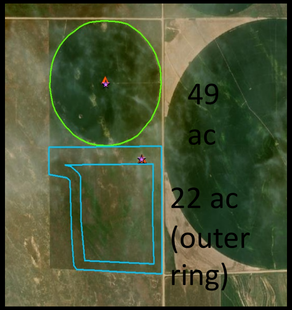
Site 3



Site 4



Site 5

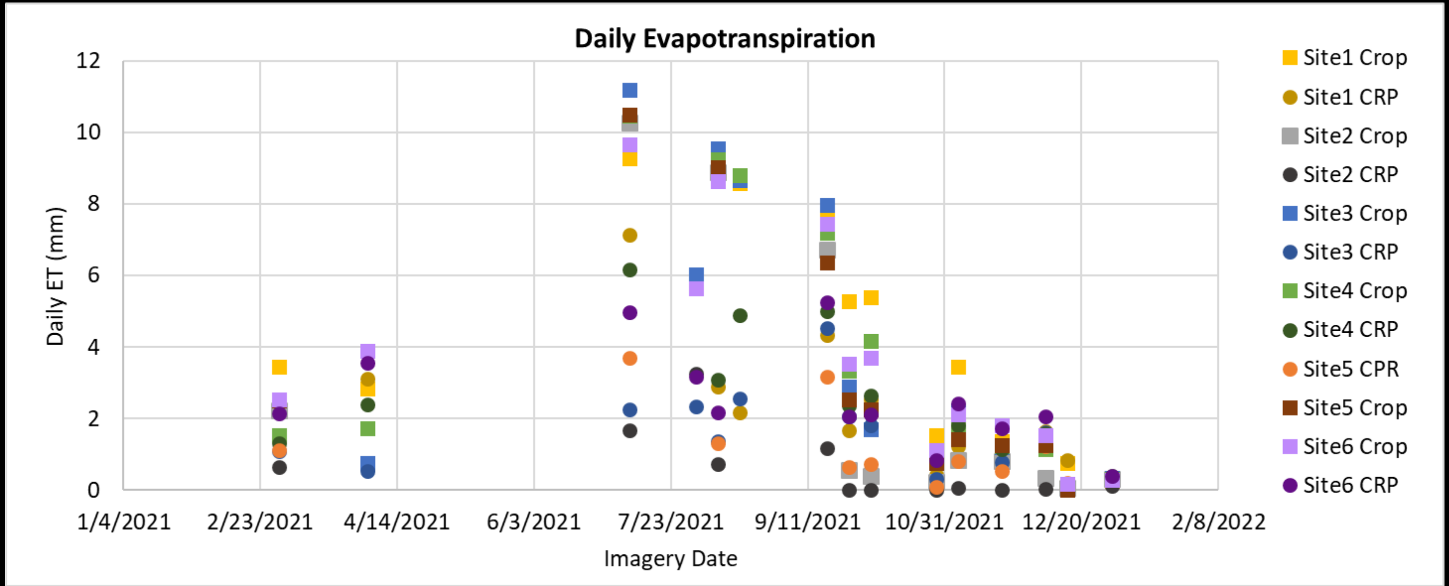


*Allen RG, Tasumi M, Trezza R. Satellite based energy balance for mapping evapotranspiration with internalized calibration (METRIC) Model. Journal of irrigation and drainage engineering. 2007 Aug;133(4):380 94.

Estimation of Evapotranspiration (ET)

NUSDA EXCHANGE

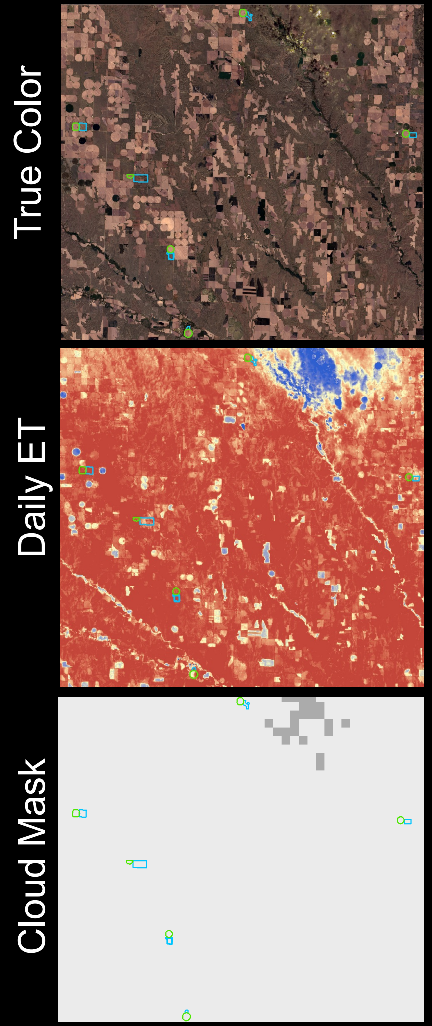
- Daily ET data was obtained from EEFLUX (version 0.20.17) using available Landsat 7, 8, and 9 imagery from 2021-2022
- Clouds, shadows and snow are masked from images prior to estimating daily ET for CRP and irrigated corn field sites
- On-farm weather stations and local Mesonet stations will be used to estimate potential daily ET using the Penman-Monteith equation



Irrigated Crop

Rain-fed CRP

Landsat 8 Image : 5/13/2021

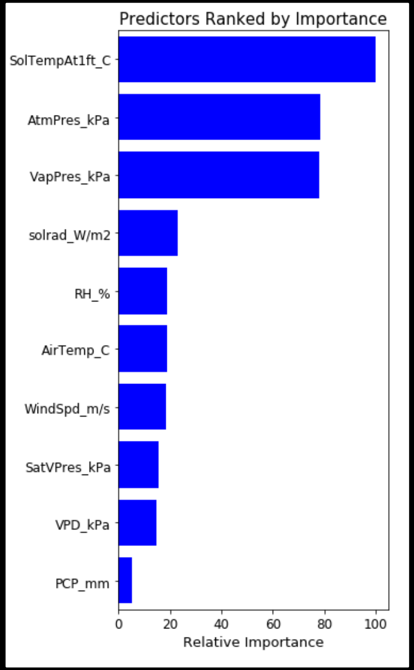


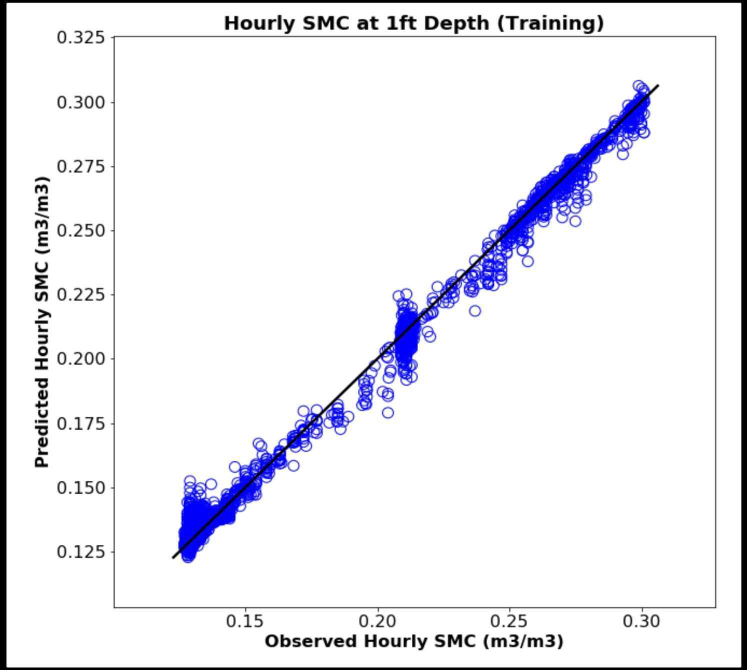
Preliminary Results: During summer months, irrigated crop fields across all sites in 2021 showcased higher ET

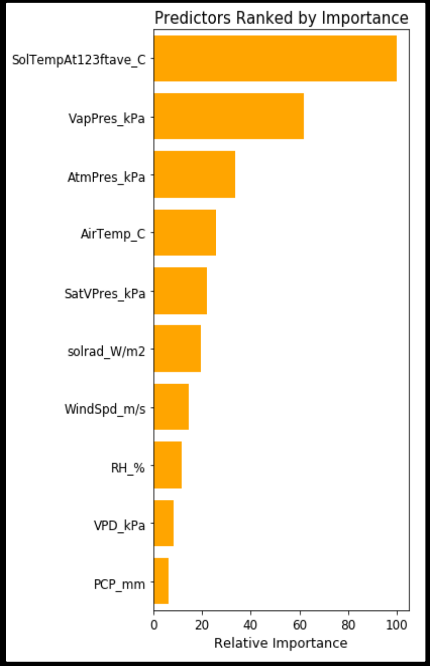
Estimation of Evapotranspiration (ET)

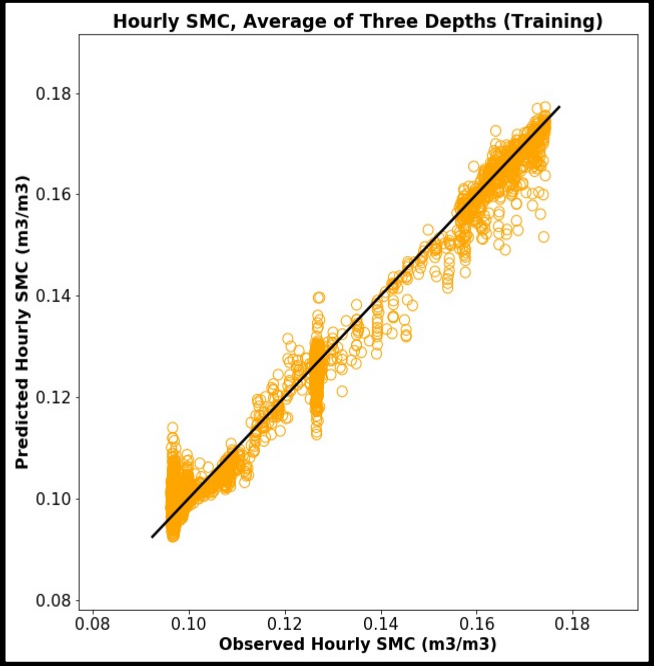
N USDA EXCHANGE

- ML-based model for predicting soil moisture content (SMC) and actual ET
  - Using datasets from several sites:
    - train ML-based model to predict daily SMC-based daily soil and weather variables, and
    - train ML-based model to predict daily ET based on daily SMC, other soil variables, weather parameters
- Preliminary results of an ML-based model (using XGBoost algorithm) for predicting hourly SMC
  - At 1 ft depth and
  - At average of three (1 ft, 2 ft, 3 ft) depths
    - Trained only on 2022 dataset for one site (Antelope, a CRP/perennial grass site)









Impacts

- Increase biomass to fuel the bioeconomy.
- Support rural socioeconomics in the Northern Great Plains region.
- Reduce unsustainable stress on the Ogallala Aquifer.
- Provide ecosystem services, especially biodiversity and reduced GHG emissions.
- Quantify economic estimates for producers considering adoption of perennials.

Summary

- On track to complete project objectives/**achieve End of Project Milestone**.
- Perennial bioenergy grasses were productive and likely established to **meet Go/No Go 1**. This will enable direct comparisons of soil properties, ecosystem services, and water use between BAU and our perennial bioenergy system.
- Preliminary results suggest **differences in ecosystem service provision between BAU and our perennial bioenergy system**, particularly for avian and arthropod abundance and diversity.

Quad Chart Overview

EXCHANGE

Timeline
October 1, 2021
September 30, 2025

	FY22 Costed	Total Award
DOE Funding	(10/01/2021 – 9/30/2025)	$3,200,000
Project Cost Share*		$800,000

TRL at Project Start: 6
TRL at Project End: 8

Project Goal

Targeted deployment of rain-fed perennial grasses to diversify crop, livestock, and bioenergy systems and enhance climate resiliency for sustainable food and energy systems and reducing management inputs.

End of Project Milestone

A 20% decrease in irrigation, fertilizer and agrochemical inputs, nutrient losses, and soil GHG emissions; 20% increase in soil organic C; greater landscape biodiversity; and delivery of new bioenergy markets in the Northern Great Plains.

Funding Mechanism

DE-FOA-0002203: FY20 Bioenergy Technologies Multi-Topic FOA; Topic Area 4: Bio-Restore: Biomass to Restore Natural Resources

Project Partners*

Pheasants Forever
Collaborating farmers

Additional Slides

Publications, Patents, Presentations, Awards, and Commercialization

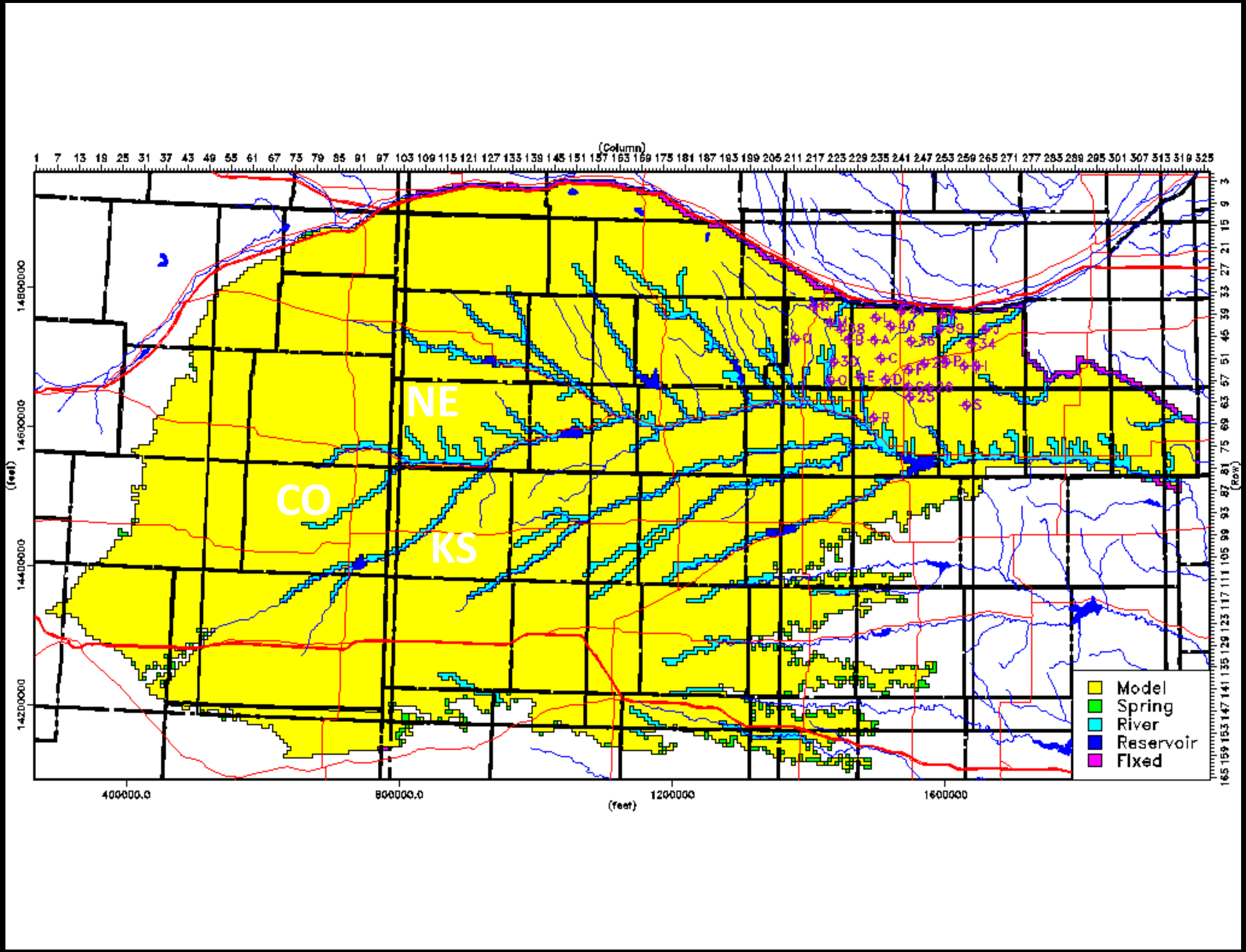
- **Presentations**
  - Stowe H, K Tam & JA Peterson. 2022. Arthropod predator community composition and activity-density in Nebraska grasslands and adjacent row crops. Annual Meeting of the ESA, Vancouver, Canada.
  - Gomez Villegas A, K Tam, H Stowe, A Smart & JA Peterson. 2022. Land use effects on pollinator composition in conservation grasslands and adjacent croplands in west central Nebraska. Annual Meeting of the ESA, Vancouver, Canada.
  - Obradovic K, H Stowe, A Gomez Villegas & JA Peterson. 2022. Abundance, diversity, and ecosystem services of dung-associated arthropod communities in croplands and adjacent grasslands of the western Great Plains. Annual Meeting of the ESA, Vancouver, Canada.
  - Stowe HE, K Tam & JA Peterson. 2022. Landscape context alters beneficial arthropod communities in Nebraska croplands. North Central Branch of the ESA, Minneapolis, MN.
  - Gomez Villegas A, K Tam, A Smart & JA Peterson. 2022. Pollinator communities in central Nebraska conservation grasslands and adjacent agroecosystems. North Central Branch of the ESA, Minneapolis, MN.
  - Strategic Bioenergy Planning: Implications for Grassland Birds, 2022 The Wildlife Society National Conference, Spokane, WA
  - Bioenergy Crop Production: Implications for Grassland Bird Communities, 2022 Pheasant Fest, Omaha, NE
  - Rangeland Vegetation Succession in Agriculture Landscapes - Understanding Wildlife Biodiversity, 2023 Cabela's Apprenticeship Poster Session, Lincoln, NE
  - Rangeland Vegetation Succession in Agriculture Landscapes - Understanding Wildlife Biodiversity, 2023 Undergraduate Creative Activities and Research Experience Poster Session, Lincoln, NE

Response to Previous Reviewers' Comments

- Not applicable

Groundwater Assessment

- The Republican River Compact Administration (RRCA) initially developed a groundwater model of the Republican River basin 20 years ago.
  - 1.2M acres irrigated
  - Nebraska, Kansas, Colorado
  - Publicly available
  - Annual updates based on pumping data
- A project goal is to modify the model to assess how the degree of conversion from irrigated row crops to rain-fed native bioenergy crops would affect groundwater levels relative to business-as-usual.
  - By adjustment of modeled pumping stresses
  - Relate RRCA results to rest of Ogallala region
  - Sustainable biomass production



Extent of Republican River groundwater model (source: republicanrivercompact.org)