Controls on carbon sequestration in native grassland

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Research Objectives & Goals

What are the consequences of global change for ecosystem function?

- Measure ecosystem carbon, water & nutrient cycling processes
- Study moisture-temperature interactions controlling ecosystem function
- Compare local case studies with regional-scale studies
General Research Strategies Employed

1) Ecosystem observational studies
   eddy covariance CO$_2$ flux measurements,
   repeat photography (PhenoCam) studies

2) Ecosystem manipulation experiments
   warmer temperature, altered rain

3) Develop and use models to predict
   ecosystem response to environmental change
Lethbridge Grassland: Fluxnet-Canada & Ameriflux
Eddy Covariance Flux Measurements
Ecosystem Carbon Balance

Net Ecosystem Carbon Exchange = Net Ecosystem Productivity (NEP)
\[ \text{NEP} = \text{GEP} - \text{TER} \]

NEP = Net Ecosystem Productivity (+/-)

GEP = Gross Ecosystem Productivity (+)

TER = Total Ecosystem Respiration (+)
Infrared heater arrays for warming ecosystem field plots

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Temperature Free-Air-Controlled Enhancement (T-FACE)
General Research Strategies Employed

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First Message

Net carbon sequestration (NEP) in grasslands varies to a large extent on an annual basis.

Mature, native grassland has the potential to sequester significant amounts of carbon for extended periods of time.
Annual net carbon exchange over 17 years measured by eddy covariance
Figure 1. Study area, grassland flux towers, and land cover over the Great Plains. The land cover map was derived from the 2001 National Land Cover Database. The numbers labeled in the Omernik Level III Ecoregions map represent the following: 1, Northern Glaciated Plains; 2, Lake Agassiz Plain; 3, Western Corn Belt Plains; 4, Central Irregular Plains; 5, Northwestern Glaciated Plains; 6, Montana Valley and Foothill; 7, Northwestern Great Plains; 8, Nebraska Sandhills; 9, Western High Plains; 10, Central Great Plains; 11, Southwestern Tablelands; 12, Flint Hills; 13, Central Oklahoma/Texas Plains; 14, Edwards Plateau; 15, Texas Blackland Prairies; 16, Western Gulf Coastal Plain; and 17, Southern Texas Plains.

Average annual NEP from 2000 to 2008 in 17 eco-regions. The error bar shows 1 standard deviation of the estimated annual NEP for the 9 years. The numbers on the x axis represent the eco-region numbers as shown in Figure 1.


The Great Plains had an average annual NEP of $24 \pm 14$ g C m$^{-2}$ yr$^{-1}$ (net sink), with annual variation in NEP ranging from 0.3 to 47.7 g C m$^{-2}$ yr$^{-1}$.

The average NEP for the entire Great Plains grassland was estimated to be 336 Tg C yr$^{-1}$ from 2000 to 2008.

In the 9 year study, including 4 dry years, the annual NEP was very variable in both space and time.

The droughts in 2000, 2002, 2006, and 2008 resulted in net carbon losses over drought-affected areas, and the Great Plains grasslands turned into a relatively low sink with NEP values of 15.8, 0.3, 20.1, and 10.2 g C m$^{-2}$ yr$^{-1}$ for the 4 years, respectively.
Second Message

Variation in moisture and moisture-temperature interactions are major factors controlling grassland net carbon sequestration.

If moisture remains near “normal” conditions, carbon sequestration can increase significantly in response to warmer conditions.
What controls annual variation in Lethbridge grassland C sequestration?

NEP = GEP – TER

Lethbridge 2013
Third Message

Despite projected increases in aridity under climate change, modeled responses predict higher grassland leaf area and productivity.

Shifts in vegetation growth to earlier spring emergence can compensate for drought-induced reduction in growth in summer time, particularly in northern regions of the Great Plains.
PHENOCAM

An ecosystem phenology web camera network

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gcc = Green/(Red+Blue+Green)
Despite increasing aridity, climate change promotes growth of North American grasslands


PhenoCam greenness observations were used to parameterize a vegetation-hydrology model (daily time-step)

The model predicted plant fractional ground coverage (fCover) – similar in concept to Leaf Area Index (LAI)

Daily changes in fCover (growing season) were strongly correlated with measurements of ecosystem photosynthesis
Relationship between plant fractional cover (fCover) and gross primary productivity (GPP) at the Lethbridge site. A fitted ordinary least squares regression is shown as a full red line.

\[ R^2 = 0.84 \ (\sim 0.16 + -9.73 \times x; \ p < 0.001) \]
Overview of the PhenoCam validation sites and their corresponding climate regimes

a. PhenoCam locations are marked with black dots. The black asterisks (*) denote the 100 random MODIS validation pixels locations within tile h10v04 (dashed polygon).

b. Climatic conditions at the PhenoCam sites as characterized by mean annual precipitation (MAP) and mean annual temperature (MAT). Note that the study area does not include significant fractions of tall grass prairie as few undisturbed tall grass prairie sites remain.

Hufkens et al. (2015) in review
Observed and predicted fCover time series for 3 sites in contrasting climate regimes and with different grassland growth dynamics

- **PhenoCam site – m**: R = 0.88
- **PhenoCam site – f**: R = 0.95
- **PhenoCam site – d**: R = 0.78

**Lower Foothills of Sierra Nevada Mtns, CA, USA**

**Lethbridge, AB, CAN**

**Jornada, NM, USA**

Hufkens et al. (2015) in review
Changes in mean annual temperature towards the end of the 21st century.

Mean annual temperature changes (°C) between the end (2090-2100) and start (2010-2020) of the 21st century for the ensemble mean of ten climate scenarios.
Changes in mean annual precipitation towards the end of the 21st century.

Mean annual precipitation changes (mm / yr⁻¹) between the end (2090-2100) and start (2010-2020) of the 21st century for the ensemble of ten climate scenarios.
Predicted changes in aridity at the end of the 21st century

Changes in the mean annual aridity index between the start (2010-2020) and the end (2090-2100) of the 21st century. Increases in the aridity index signify increased aridity.

Aridity Index = mean annual potential evapo-transpiration/ mean annual precipitation

Coupled Model Inter-comparison Project Phase 5 (CMIP5)
Predicted changes in grassland fractional cover at the end of the 21st century

Change in mean annual grassland plant fractional cover between the end (2090-2100) and the start (2010-2020) of the 21st century.
Despite increasing aridity, climate change promotes growth of North American grasslands


Model calculations indicate a 23% increase in annual grassland fCover by the year 2100 (integral of daily fCover over the year)

Warmer and wetter springtime led to earlier and higher peak productivity, particularly in the northern portion of the study area

Model predictions at the Lethbridge site indicate an average increase in GEP of 121 g C m\(^{-2}\) yr\(^{-1}\) by the year 2100 (mean GEP ± SD = 500 ± 240 g C m\(^{-2}\) yr\(^{-1}\))
Summary & Conclusions

• Mature, native grassland has the potential to sequester significant amounts of carbon for extended periods of time

• Variation in moisture and moisture-temperature interactions are major factors controlling grassland net carbon sequestration

• Despite projected increases in aridity under future climate change, modeled responses predict higher grassland leaf area and GEP