Response of plant biomass production and soil respiration to experimental warming and precipitation manipulation in a northern Great Plains grassland

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University of Lethbridge
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Global Change and Ecosystems


REVIEW

Responses of terrestrial ecosystems to temperature and precipitation change: a meta-analysis of experimental manipulation

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“New experiments with combined temperature and precipitation manipulations are needed to conclusively determine the importance of temperature-precipitation interactions on the C balance of terrestrial ecosystems under future climate conditions.”

“Complex interactions do exist (between temperature-precipitation) and may not be consistent among ecosystems and treatments.”
Grasslands of the Great Plains (Ostlie et al. 1997)
Lethbridge Grassland: Associate Site in Fluxnet-Canada
Interaction between moisture and temperature in mixed grass prairie

Interaction between moisture and temperature in mixed grass prairie

Flanagan & Johnson (2005) AgForMet 130: 237
Research Approaches

1) Ecosystem CO₂ & H₂O flux measurements in response to annual weather variation

2) Ecosystem manipulation experiments
   altered temperature
   altered summer rain amounts
Manipulation Experiments 2011: Temperature (2) & Precipitation (3)

- open-top chambers (warm) vs. control
- rain-out shelters (minus)
- precipitation addition (plus) vs. ambient

2 x 3 factorial experiment

2012 only Temperature Treatments
July 2011

Warm – Control at 14:00 hours
Comparison of cumulative growing-degree-days (GDD) during March-September in 2011 and 2012.

Normal represents the 30-year average ± SD for 1971-2000.

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>Normal ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1642</td>
<td>1769</td>
<td>1697 ± 118</td>
</tr>
<tr>
<td>Warm</td>
<td>1776</td>
<td>2028</td>
<td></td>
</tr>
<tr>
<td>GDD Difference (Warm – Control)</td>
<td>134</td>
<td>259</td>
<td></td>
</tr>
</tbody>
</table>

\[
GDD = \sum \max (T_{Avg} - 5, 0^\circ C)
\]
2011

Volumetric Soil Water Content (m$^3$ m$^{-3}$)

- May
- June
- July
- August

Precipitation Treatment: Minus, Ambient, Plus

Control
Warm

0-30 cm depth
Comparison of total precipitation (P) during May-October in Lethbridge.

<table>
<thead>
<tr>
<th>Year</th>
<th>P (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>240</td>
</tr>
<tr>
<td>2011</td>
<td>323</td>
</tr>
<tr>
<td>2012</td>
<td>256</td>
</tr>
<tr>
<td>Normal</td>
<td>268</td>
</tr>
</tbody>
</table>

1999 – close to normal temperature and precipitation conditions
Ecosystem Eddy Covariance Fluxes in 2011 and 2012

![Graphs showing ecosystem eddy covariance fluxes in 2011 and 2012.](image)
Comparison of integrated carbon flux rates (g C m$^{-2}$ period$^{-1}$) during May-September calculated based on eddy covariance measurements during 2011 and 2012.

Error bars represent ± uncertainty values.

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiration (TER)</td>
<td>350 ± 15</td>
<td>296 ± 13</td>
</tr>
<tr>
<td>Photosynthesis (GEP)</td>
<td>562 ± 16</td>
<td>487 ± 14</td>
</tr>
<tr>
<td>Net Uptake (NEP)</td>
<td>212 ± 6</td>
<td>192 ± 6</td>
</tr>
</tbody>
</table>

NEP = GPP - TER
Hypothesis:  **BIOMASS PRODUCTION**

Warmer temperatures will stimulate increased biomass production, particularly given the high precipitation and soil moisture content in 2011 and 2012.
2011

![Graph showing aboveground biomass for July 12 and August 2 with control and warm treatments.]

2012

![Graph showing aboveground biomass for July 19 with control and warm treatments.]

**Aboveground Biomass (g m⁻²)**

**Treatment**

- Control
- Warm
RESULTS:

What effect did warmer temperature have on grassland BIOMASS PRODUCTION?

• no significant temperature treatment effect on biomass production in 2011 or 2012

DISCUSSION:

• aboveground biomass production may have been at a ceiling imposed by nutrient limitation

• nutrient limitation was imposed because of relatively high precipitation and water availability in both 2011 and 2012
2011

a) July 12

Aboveground Biomass (g m\(^{-2}\))

<table>
<thead>
<tr>
<th>Precipitation Treatment</th>
<th>Control</th>
<th>Warm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) August 2

Aboveground Biomass (g m\(^{-2}\))

<table>
<thead>
<tr>
<th>Precipitation Treatment</th>
<th>Control</th>
<th>Warm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minus</td>
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<td>Ambient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plus</td>
<td></td>
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</tbody>
</table>

2012

July 19

Aboveground Biomass (g m\(^{-2}\))

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control</th>
<th>Warm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

The graphs illustrate the aboveground biomass for different precipitation treatments in 2011 and 2012, with a distinction between control and warm conditions.
Ceiling on shoot growth

Due to N-limitation as suggested by lower tissue N concentration in years with high biomass
DISCUSSION:

What effect did warmer temperature have on grassland BIOMASS PRODUCTION?

• aboveground biomass production may have been at a ceiling imposed by nutrient limitation

HYPOTHESIS:

• nutrient limitation may have stimulated allocation of carbon to roots, mycorrhizae and exudates, particularly after the peak of shoot growth
Hypothesis: **SOIL RESPIRATION RATE**

The magnitude of the treatment temperature increase is too small to **DIRECTLY** cause a significant increase in soil respiration rate (mean 2.5°C increase at midday).

Soil respiration will be stimulated **INDIRECTLY** via an increase in carbon allocation belowground to roots, mycorrhizae and exudates.
Comparison of integrated carbon flux rates calculated based on chamber soil respiration measurements for control and warmed treatment plots and total ecosystem respiration from eddy covariance measurements during 2011 and 2012.

Error bars represent ± uncertainty values.

<table>
<thead>
<tr>
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<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chamber Respiration (July-September)</strong></td>
<td>(g C m⁻² period⁻¹)</td>
<td>(g C m⁻² period⁻¹)</td>
</tr>
<tr>
<td>Control</td>
<td>219 ± 76</td>
<td>155 ± 46</td>
</tr>
<tr>
<td>Warm</td>
<td>716 ± 225</td>
<td>341 ± 99</td>
</tr>
<tr>
<td><strong>Eddy Covariance (July-September)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecosystem Respiration</td>
<td>214 ± 9</td>
<td>185 ± 8</td>
</tr>
</tbody>
</table>
Dynamic Closed Chamber for CO₂ Exchange Measurements in Treatment Plots

Net Ecosystem CO₂ Exchange and Total Ecosystem Respiration (in darkened chamber)
RESULTS:

What effect did warmer temperature have on grassland soil respiration rate?

• soil respiration was increased after the peak of shoot growth in the warm treatment

• cumulative soil respiration during July-Sept was doubled (2012) or tripled (2011) by the warm treatment

• carbon lost in soil respiration was higher in 2011 likely because of greater precipitation in that year
CONCLUSION:

What effect did warmer temperature have on grassland soil respiration rate?

- The observed increase in soil respiration was too large to be explained only by a direct effect of temperature-stimulated metabolism.

- Soil respiration was likely increased indirectly by greater carbon allocation belowground to roots, mycorrhizae and exudates because of the hypothesized nutrient-limitation of shoot growth.
What unintended effects do open-top chambers have on environmental conditions?

- reduced solar radiation: measured at ~5% reduction in PPFD
- reduced soil moisture content: no significant effect in 2011 and 2012
- higher vapor pressure deficit:
- reduced wind speed: likely the most important unintended effect
What effect does reduced wind speed have on plant growth?

- increases leaf area and plant relative growth rate
- decreases root/shoot ratio