Soil respiration dynamics under reduced throughfall in a dry temperate Eucalypt forest (Wombat State Forest)

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Benedikt Fest, Stephen J. Livesley, Stefan K. Arndt
Soil respiration - Background

- major CO$_2$ efflux of terrestrial ecosystems to the atmosphere ($\sim$ 60 PgCyr$^{-1}$) – compare → fossil fuel emissions: 7.7 PgCyr$^{-1}$
- critical role in the global (forest) carbon cycle & it’s carbon sink strength
- strong dependence on
  → soil temperature (increase with increasing temperature)
  → soil moisture (decrease outside optimum range)
  → substrate quality & quantity
- climate change predictions for SE-Australia:
  → increase in temperature
  → overall decrease in rainfall – change of rainfall pattern (intensity, frequency)

- difficulty in predicting responses of soil respiration in forest ecosystems to changing environmental conditions
- RA and RH: different responses (sensitivity) to environmental changes, e.g. soil temperature and moisture
- important to understand processes underlying soil respiration and to identify its controls thereof
Research Objectives

- Throughfall (or rainfall) manipulation experiments – minimize confounding effects of environmental drivers

- Throughfall manipulation experiments worldwide focused so far on:
  - exclusion of throughfall
  - responses of total soil respiration
  - single growing season

1) seasonal variability of SR, RH and RA

2) their dependence on soil temperature and soil moisture

3) effect of a long-term throughfall reduction upon soil respiration dynamics

4) the relative contribution of RH and RA to SR patterns in a temperate broadleaved evergreen forest.
Experimental design

- Throughfall reduction (~ 40%, TFR)
- 3 Plots as Control, 3 Plots with TFR (20 x 20 m)
- partitioning of RH and RA – *root exclusion*
- 10 chambers/ treatment/ plot
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- **measured fluxes:**
  - SR – Soil respiration (total)
  - RH – Heterotrophic respiration
  - SR – RH ⇒ RA – Autotrophic respiration
Experimental design

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**measured fluxes:**
- **SR** – Soil respiration (total)
- **RH** – Heterotrophic respiration
- **SR** – RH ⇒ **RA** – Autotrophic respiration

- monthly measurements of CO₂ (CH₄, water vapour) with dynamic closed chambers linked to a Fast Greenhouse Gas Analyser (FGGA, LGR)
- corresponding measurements of soil moisture and soil temperature during soil respiration measurements & automated measurements
Component fluxes – Control plot

mean μmolCO$_2$m$^{-2}$s$^{-1}$
SR: 4.69 ± 0.24
RH: 2.20 ± 0.19
RA: 2.49 ± 0.20
Component fluxes – Control plot

mean µmolCO₂ m⁻² s⁻¹
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Component fluxes – Control plot

**a)**
- SR: 4.69 ± 0.24
- RH: 2.20 ± 0.19
- RA: 2.49 ± 0.20

**b)**
- Automatically measured daily mean
- Manually measured daily mean

**c)**
- Soil moisture (v/v)

**d)**
- Monthly throughfall (mm)

**mean µmolCO₂m⁻²s⁻¹**
- SR: 4.69 ± 0.24
- RH: 2.20 ± 0.19
- RA: 2.49 ± 0.20

**annual rainfall (mm)**
- 142 yr 871
- 1997-2009 760
- 2010 1250
- 2011 1059
Effect of reduced throughfall

SR

-19.0% *

A) SR

F₁,₆ = 9.22, P = 0.044

D) SR

F₁,₇₆ = 88.72, P = <0.001

-13.5% *
Effect of reduced throughfall

SR
-19.0% *

RH
+ 5.5 %
Effect of reduced throughfall

**SR**
-19.0% *

**RH**
+ 5.5 %

**RA**
-40.7% *

- **SR**
  - TFR
  - Control

- **RH**
  - F₁,₃₈.₄ = 2.72, P = 0.107
  - F₁,₃₈₉ = 79.27, P = <0.001
  - -13.5% *

- **RA**
  - F₁,₃₇ = 9.68, P = 0.040
  - F₁,38.₄ = 2.72, P = 0.107
  - -10.0% *

- **Soil moisture (v/v)**

- **Soil respiration (µmol CO₂ m⁻² s⁻¹)**
mean relative contribution of RH to SR:

47% (27-75%) in the Control

61% (28-96%) in TFR
Temperature sensitivity

Lloyd & Taylor (1994):

\[ E * \left( \frac{1}{T_{ref} - T_0} - \frac{1}{T_s - T_0} \right) \]

\[ R = R_{ref} * e \]

\[ \text{T}_{ref} : 10^\circ C \]

<table>
<thead>
<tr>
<th></th>
<th>a) Lloyd &amp; Taylor</th>
<th>b) Q_{10} function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R_{ref}</td>
<td>E</td>
</tr>
<tr>
<td>Control</td>
<td>SR</td>
<td>4.45 ± 0.18</td>
</tr>
<tr>
<td></td>
<td>RH</td>
<td>1.84 ± 0.08</td>
</tr>
<tr>
<td></td>
<td>RA</td>
<td>2.52 ± 0.16</td>
</tr>
<tr>
<td>TFR</td>
<td>SR</td>
<td>3.54 ± 0.12</td>
</tr>
<tr>
<td></td>
<td>RH</td>
<td>1.88 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>RA</td>
<td>1.60 ± 0.12</td>
</tr>
</tbody>
</table>

significance level: *** <0.001, ** <0.01, * <0.5, n.s. not significant

\[ Q_{10} \text{ function:} \]

\[ R = R_{ref} * Q_{10} \]

\[ \frac{(T_s - T_{ref})}{10} \]
Soil moisture dependency

Soil moisture (v/v)

SR

RH

RA

Q: adj. $R^2 = 0.51$, $P < 0.001$
L: adj. $R^2 = 0.51$, $P < 0.001$

$R^2 = 0.24$, $P < 0.001$
L: adj. $R^2 = 0.01$, n.s.

$Q: adj. R^2 = 0.30, P < 0.001$
L: adj. $R^2 = 0.14, P = 0.003$

Soil temperature ($^\circ$C)

$b) Q: adj. R^2 = 0.03$, n.s.
L: adj. $R^2 = 0.02$, n.s.

d) $Q: adj. R^2 = 0.43, P < 0.001$
L: adj. $R^2 = 0.44, P < 0.001$

e) $Q: adj. R^2 = 0.24, P < 0.001$
L: adj. $R^2 = 0.01$, n.s.

Soil moisture norm. soil respiration (mol CO$_2$ m$^{-2}$ s$^{-1}$)

Control

TFR
## Soil moisture dependency

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>TFR</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>SR</td>
<td>RH</td>
</tr>
<tr>
<td>Summer months</td>
<td>adj.R²</td>
<td>P n</td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>**</td>
</tr>
<tr>
<td>All months except summer</td>
<td>adj.R²</td>
<td>P n</td>
</tr>
<tr>
<td></td>
<td>0.26¹***</td>
<td>0.37¹***</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

¹ negative correlation; ² best fit quadratic regression; significance level: *** <0.001, ** <0.01, * <0.5, n.s. not significant

- soil moisture alone did not explain the strong decrease of RA during summer months in the Control
- changes in RA often occur concurrently with changes in fine root and aboveground plant growth – possible reduced fine root growth
- no correlation between GPP, VPD or PAR and soil respiration fluxes in the Control
- likely plant internal carbon allocation → ‘phenological programming’ (Joslin et al. 2001, Mission et al., 2006; Hendrick and Pregitzer 1996)
strong seasonality – SR result of distinct seasonal patterns of RH and RA

spring flush in SR due to strong increase in RA - increased growth after decade long drought periods

strong decrease in RA during summer – possible reduced fine root growth - low soil moisture & plant internal carbon allocation

interannual variability in soil respiration fluxes – different rainfall pattern

RH strongly dependent on soil temperature, no dependence on soil moisture

RA no apparent temperature sensitivity, partly dependent on soil moisture

Throughfall reduction (40%) → greatest effect on RA (-41%) – summer & spring 2011
→ no effect on RH
→ reduction in SR (-19%) – spring & summer 2011
⇒ possible reduction in fine root growth

main relative determinant of SR:
RA in Control (53%) and RH under reduced throughfall (61%)
long-term throughfall manipulation experiments important to address seasonal and interannual variability in rainfall and responses of soil respiration processes

in combination with partitioning of soil respiration into its component fluxes - strength to improve process based forest ecosystem models and to make more realistic predictions that include consideration of climate change carbon cycle feedbacks.

Reduction in rainfall will lead to overall decrease of soil respiration in temperate broadleaved evergreen forests but the magnitude influenced by seasonal and interannual climate variability which can only be overcome by long-term climate manipulation experiments.

Ultimate effect of climate change on the forest’s carbon balance - dependence on direct response of plant productivity and indirectly due to its influence upon soil respiration dynamics.
Thanks to:

Julio Najera
Anne-Sophie Leclercq
Pierrick Pigot
Pierre Du-Buit
Xin Kun
Laurie Beroule
Mathilde Lepee
Maja Dietrich

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often strong & significant relationships between RH and /or TSR with GPP, VPD, PAR or Tair

but Autocorrelation with soil temperature:
Tair (R = 0.96)
PAR (R = 0.86)
VPD (R = 0.85)
GPP (R = 0.84).

confounded by strong relationships between soil respiration rates and soil temperature
Table 1  Main site characteristics of the Wombat State Forest, Victoria, Australia

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main species</td>
<td>Eucalyptus (E. obliqua, E.rubida, E.radiata)</td>
</tr>
<tr>
<td>Longitude</td>
<td>144° 05' E</td>
</tr>
<tr>
<td>Latitude</td>
<td>37° 25' S</td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>706</td>
</tr>
<tr>
<td>Total Area (ha)</td>
<td>70000</td>
</tr>
<tr>
<td>Mean annual temperature (°C)</td>
<td>12.1 ± 0.1</td>
</tr>
<tr>
<td>Mean annual rainfall (142 yrs, mm)</td>
<td>871 ± 16</td>
</tr>
<tr>
<td>2011 annual rainfall (mm)</td>
<td>1059</td>
</tr>
</tbody>
</table>

**Soil characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type</td>
<td>podzolic, silty clays overlying clays</td>
</tr>
<tr>
<td>Soil depth (cm)</td>
<td>50cm</td>
</tr>
<tr>
<td>Root depth (&gt;80% of root biomass, cm)</td>
<td>0-30 cm</td>
</tr>
<tr>
<td>pH</td>
<td>4.83 ± 0.02</td>
</tr>
<tr>
<td>EC (mS cm⁻¹)</td>
<td>0.064 ± 0.002</td>
</tr>
<tr>
<td>C/N</td>
<td>30.9 ± 0.5</td>
</tr>
<tr>
<td>Bulk density (0-10 cm, kg m⁻³)</td>
<td>0.94 ± 0.02</td>
</tr>
<tr>
<td>% sand</td>
<td>45.4 ± 1.8</td>
</tr>
<tr>
<td>% silt</td>
<td>27.9 ± 1.9</td>
</tr>
<tr>
<td>% clay</td>
<td>26.7 ± 0.4</td>
</tr>
</tbody>
</table>

**Stand characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litterfall (g m⁻² yr⁻¹)</td>
<td>1120 ± 52</td>
</tr>
<tr>
<td>Litterdecomposition (g g⁻¹ yr⁻¹)</td>
<td>0.75 ± 0.02</td>
</tr>
<tr>
<td>Tree density (ha⁻¹)</td>
<td>1316*</td>
</tr>
<tr>
<td>Tree dbh (cm)</td>
<td>18.6*</td>
</tr>
<tr>
<td>Tree height (m)</td>
<td>15*</td>
</tr>
<tr>
<td>LAI (leaf area index m² m⁻²)</td>
<td>1.81*</td>
</tr>
</tbody>
</table>

where applicable: mean of n = 3 ± 1SE; * Moore (2011)