How does N deposition reduce C sequestration in subalpine grassland soil?

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Prologue

- Air pollution in the form of atmospheric N deposition can increase plant productivity and thus soil C acquisition potential.

- But it may also increase respiratory C losses from autotrophic and heterotrophic metabolism, offsetting any net increase in C storage.

> Vegetation response to global change is not a safe proxy for the terrestrial C sink
The Alp Flix Experiment

Effect of 7 years of increased atmospheric N deposition on
• Productivity
• Ecosystem CO$_2$-exchange
• Soil C pools and isotopic signatures

... of a species rich, subalpine pasture

Reduced C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence
Experimental setup

Nitrogen treatments
on 9 plots × 20 subplots/turf monoliths

\[ \text{N4} = \text{ambient deposition} (< 4 \text{ kg ha}^{-1} \text{ y}^{-1} \text{ wet and dry background}) \]
\[ \text{N9} = + \ 5 \text{ kg} \]
\[ \text{N14} = + \ 10 \text{ kg} \]
\[ \text{N29} = + \ 25 \text{ kg} \]
\[ \text{N54} = + \ 50 \text{ kg} \]

() = not included in soil density fractionation and \[ ^{13}/^{12} \text{C isotope analysis} \]
Plant yield response to N deposition: Consistently increasing with N dose

(Volk et al. Biogeosciences 2016)
Soil org. C response to N deposition: Maximum response at low N dose

Reduced C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence

(Volk et al. Biogeosciences 2016)
NEP\textsubscript{cum} response to N deposition: Maximum response at low N dose

Reduced C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence

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Reasons for reduced [SOC]

N deposition changed the shoot/root ratio only marginally from N4\textsubscript{control} (S/R= 0.22) to N14 (S/R= 0.23).

But S/R increased quite dramatically in N54 (S/R= 0.29), equivalent to a 24% smaller root proportion of total biomass in N54.

In NEE, N deposition favors $R_{\text{eco}}$ over GPP:
For cumulative C loss from $R_{\text{eco}}$ the step from N14 to N54 treatment is equivalent to a factor 1.8 increase.

But GPP increases only by a factor of 1.1 between the N14 and N54 treatment level.

(Volk et al., Env Poll, 2014)
Some light in the black box

Illustrating in detail the carbon fluxes into and out of the Alp Flix subalpine grassland soil:

- We tracked seasonal dynamics of $\delta^{13}C$ signatures of soil respired CO$_2$ from soil gas-wells.

- Bulk soil was separated into 4 density fractions. These fractions represent distinct (but artificial) classes of soil organic matter pools.

- Resulting distinct SOC pools were analyzed for $\delta^{13}C$ signatures and C concentration.
Why isotopic signatures?

Environmental conditions during the assimilation of CO₂ from the atmosphere create a characteristic δ¹³C fingerprint.

¹³C discrimination is reliably correlated with temperature, plant water availability and productivity.

This is because conditions that reduce mesophyll CO₂ concentration shift the discrimination (through diffusion effects) toward -4‰, while high mesophyll CO₂ concentrations shift the discrimination (through carboxylation) toward -30‰.
Seasonal differences in discrimination are reflected in soil respired CO$_2$

Lisa Wingate et al. 2010 New Phyt.

Photosynthetic carbon isotope discrimination and its relationship to the carbon isotope signals of stem, soil and ecosystem respiration

Reduced C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence
What seasonal dynamics? (picture is a little misleading ;-)

May

June

August

September
Soil resp. $\delta^{13}$C CO$_2$ seasonal dynamics

Reduced C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence

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Soil resp. δ\textsuperscript{13}C CO\textsubscript{2} seasonal dynamics

Reduced C sequestration under N deposition: Soil fraction and \textsuperscript{13}C isotope evidence

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Preferential use of $^{12}$C in respiration: The remaining C is less $^{13}$C depleted

Fig. 2 Changes in $\delta^{13}$C signatures in all individual plots at the five sites plotted against the natural logarithm of the fraction of C remaining
Radiocarbon evidence: $\delta^{13}C$ is a valid proxy for OM age

Figure 7: Relationship between $\delta^{13}C$ and $\Delta^{14}C$ in different layers from five forested podzolic soils in Scotland. Each symbol corresponds to one profile. (Redrawn from data in Ref. 53.)

Balesdent and Mariotti 1996
Data redrawn from
SJ Ladyman and DD Harkness, Radiocarbon 1980
[C] and $d^{13}C$ highly correlated across soil density fractions 2003

Reduced C sequestration under N deposition: Soil fraction and $^{13}C$ isotope evidence

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Light soil fractions with C gains, heavy fractions with C losses after 7 years

**A) 2003**

\[ f = y_0 + a \times x \]

- **R**: 0.9672
- **R^2**: 0.9355
- **Adj R^2**: 0.9139
- **Std. Error**: 0.1600

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**B) 2010**

\[ f = y_0 + a \times x \]

- **R**: 0.9754
- **R^2**: 0.9514
- **Adj R^2**: 0.9352
- **Std. Error**: 0.1989

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Reduced C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence

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Higher C gains / lower losses at low N deposition rate

Reduction in C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence
Stronger $^{13}$C depletion at low N deposition rate

Reduced C sequestration under N deposition: Soil fraction and $^{13}$C isotope evidence
Conclusion

Surprisingly, heavy soil fractions (old/recalcitrant organic matter) are losing C, despite an overall bulk soil C gain in all treatments.
But the depletion of $\delta^{13}$C$_{SOC}$ was significantly higher in the low N14 compared to the high N54 treatment.

This is indicative of a larger input of new C and/or reduced mobilization of previously protected organic matter at the low N14 deposition rate.

Thus, in a period of bulk soil C acquisition, low N14 input was more effective in promoting C gains in ‘young’ OM pools and reducing C losses in ‘old’ OM pools compared to the high N54 input.
Reduced GPP and R eco CO$_2$ flux, but no ecosystem C loss under elevated O$_3$

Thank you for your attention 😊

(Picture: the research site on a winter morning)