Stimulation of soil N cycling after two years of Free Air CO_2 Enrichment increases nitrous oxide emissions in a temperate forest, UK.

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ABSTRACT

Increasing atmospheric CO_2 concentrations in temperate forests may affect soil nitrogen (N) cycling processes due to the increased demand for nitrogen by trees to support CO_2 uptake through photosynthesis.

We have measured gross rates of N mineralisation, nitrification, asymbiotic nitrogen fixation and source partitioned N_2O production in a Free-Air CO_2 Enrichment (FACE) facility in a mature temperate oak dominated forest.

Following the first year of CO_2 fumigation, there were indications of soil N limitation. However, after only 2 years of the FACE experiment there is strong evidence of a shift in key soil N processes to sustain the enhanced nutrient demands to support enhanced canopy CO_2 uptake.

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INTRODUCTION

Increasing atmospheric CO_2 concentrations in temperate forests may affect soil nitrogen (N) cycling processes due to the increased demand for nitrogen availability by trees to support CO_2 uptake through photosynthesis. This in turn can affect the emission of nitrous oxide (N_2O) from the forest soil leading to a potential trade-off between the enhanced canopy CO_2 uptake and soil N2O emission.

The Birmingham Institute of Forest Research (BIFoR) established a Free-Air CO_2 Enrichment (FACE) facility in 2017 in a mature temperate oak dominated forest to study under 'real world' conditions the risks of a changing climate to forest ecosystems and the services they provide.

We hypothesised that N mineralisation and N_2O production would increase as a consequence of CO_2 fumigation.

Figure 1: The BiFOR FACE facility in a mature oak woodland in Staffordshire, UK.

STUDY SITE AND METHODS

In April 2018 and again in May 2019, two years after the start of fumigation with 550 ppm CO_2, we collected soil samples (0 – 15 cm depth) from the three elevated CO_2 (eCO_2) and three control plots.(Fig. 1).

Soils were amended in the laboratory with 98 at % ^{15}N-NH_4^+ and ^{15}N-NO_3^- (at ~20 % of the ambient soil NH_4^+ and NO_3^- concentration) and were incubated in the dark for 24 hours. Gross N mineralisation and nitrification were estimated according to the isotope dilution technique, while N_2O emission from nitrification (^{15}N-NH_4^+ treatment) and denitrification (^{15}N-NO_3^- treatment) were estimated according to the ^{15}N Gas-Flux method. Additionally, C/N ratio and $\delta^{15}N$ and $\delta^{13}C$ were measured in unamended eCO_2 and control samples via EA-IRMS.

RESULTS AND DISCUSSION

Whilst gross N mineralisation and N_2O emission were only marginally higher in eCO_2 plots compared to controls after one year of fumigation, there was a significant stimulation of N cycling after the second year that led to more pronounced differences.

Gross N mineralisation rates doubled in the eCO_2 plots compared to the control plots, while a similar twofold increase was observed for gross nitrification rates ($p < 0.05$). Ammonia immobilisation was not significantly different but dominated (~70 %) ammonia consumption pointing towards N limitation in these forest soils (Fig.1).

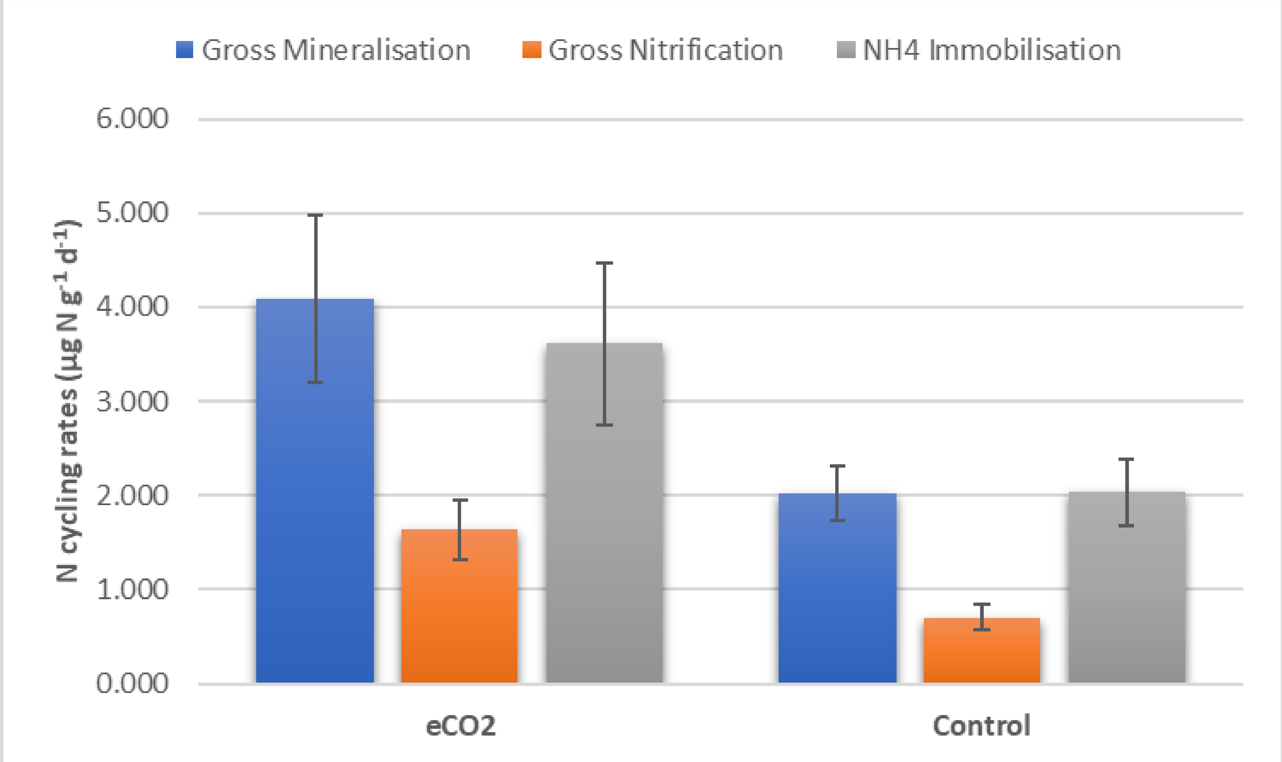

Figure 1: Mean ± SE gross rates of mineralisation, nitrification and ammonia immobilisation two years after the start of fumigation with 550 ppm CO_2

The observed stimulation in N cycling was further corroborated by the significantly enriched $\delta^{15}N$ signal (mean -0.66 ‰) in eCO_2 plots compared to the controls (mean -1.38‰). Moreover, the eCO_2 samples had a more depleted $\delta^{13}C$ signal (mean -28.37 ‰) compared to the controls (mean -27.99 ‰), probably as a result of the additional carbon supplied through fumigation (CO_2: $\delta^{13}C$ ~ -28 ‰).

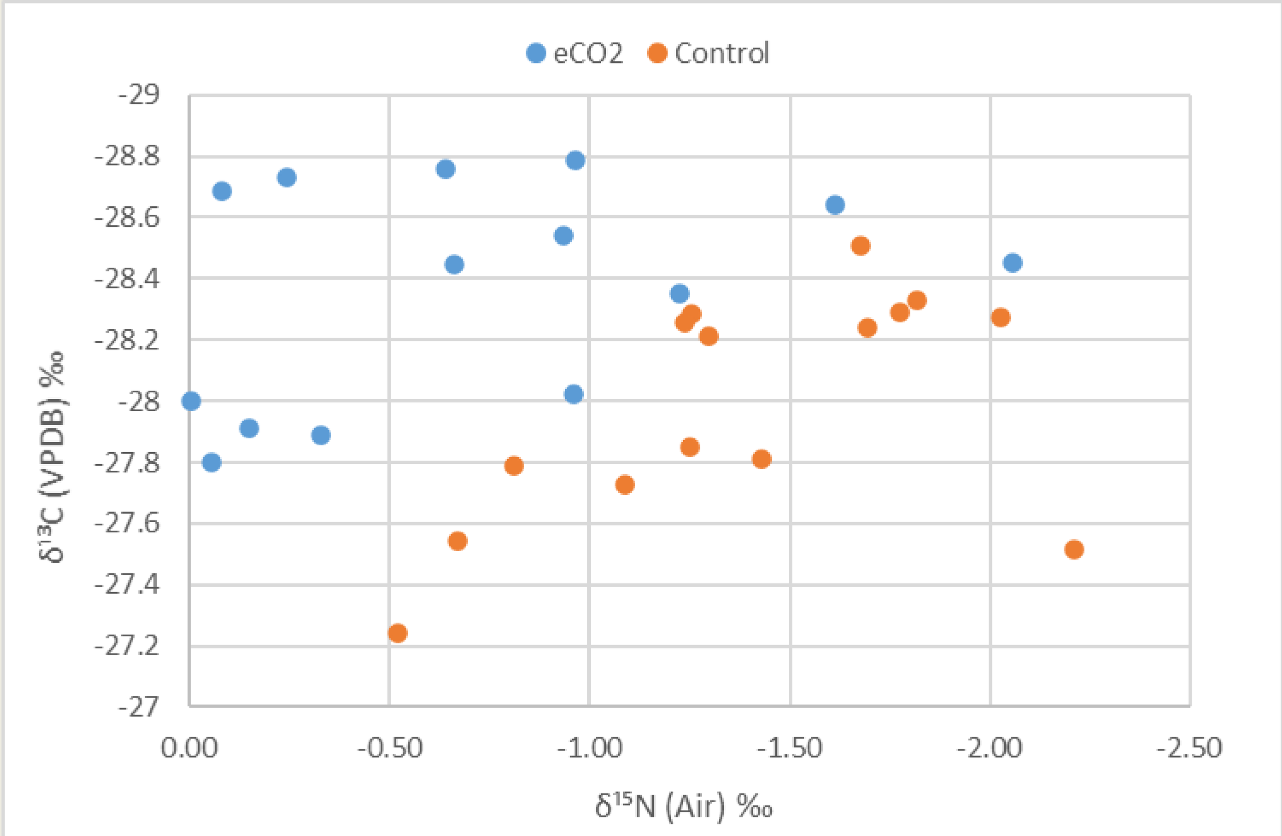

Figure 2: Natural abundance $\delta^{15}N$ and $\delta^{13}C$ in eCO_2 and control in unamended forest soil samples.

N_2O emission from both denitrification and nitrification were significantly higher (almost double) in eCO_2 compared to the control plots (Fig. 3). Both processes contributed roughly equally to the increase of total N_2O emission in CO_2 fumigated forest soils.

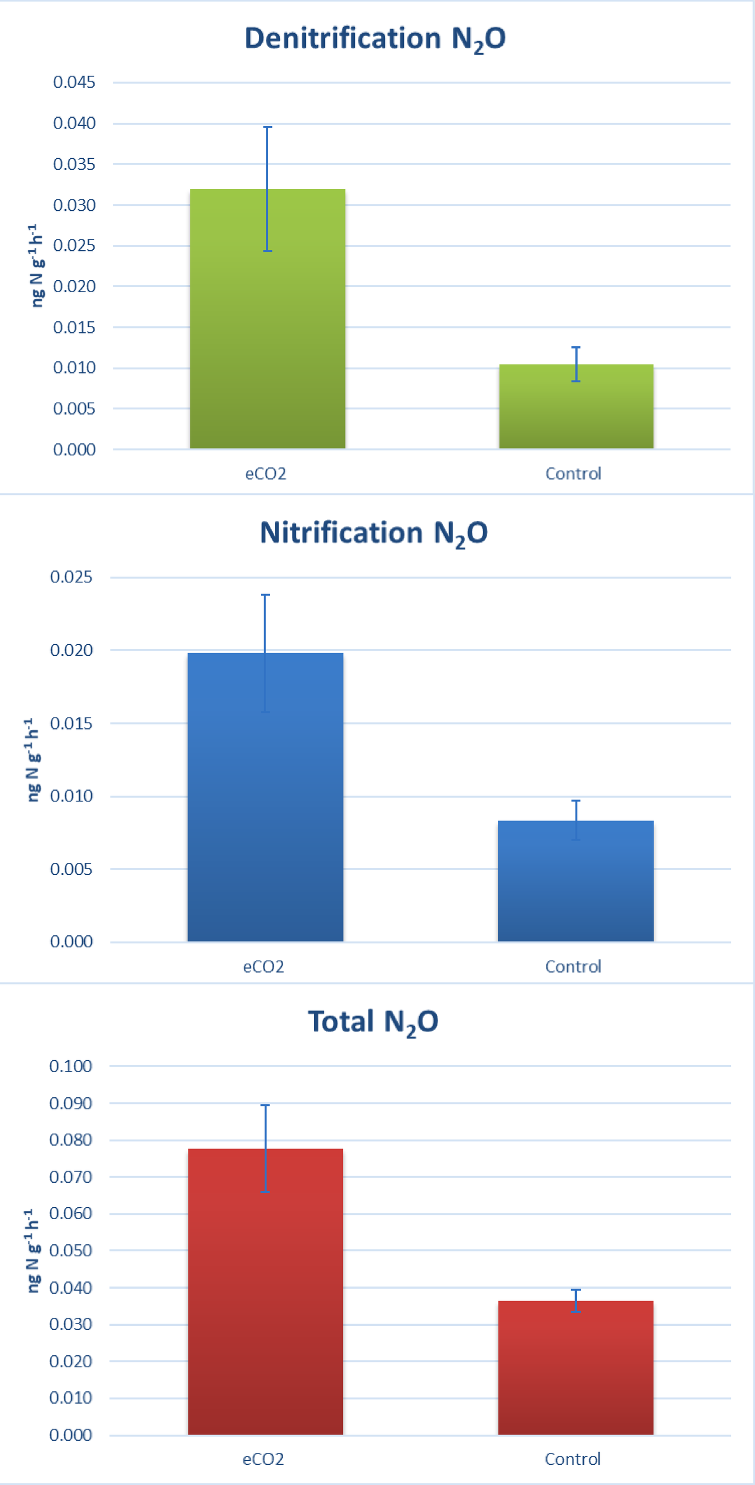

Figure 4: Mean ± SE rate of N_2O production from nitrification and denitrification sources and total N_2O emission.

CONCLUSIONS

- ❑ Soil N limitation was observed after 1 year of CO_2 fumigation due to the increased demand for nitrogen availability by trees to support CO_2 uptake through photosynthesis.
- ❑ Subsequently a shift in key N transformation processes was observed in the 2nd year with significantly increased gross mineralisation and nitrification rates in fumigated plots.
- ❑ N_2O emissions by both denitrification and nitrification also increased in response to CO_2 fumigation .

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