Supporting information: Long-term ecosystem nitrogen limitation from foliar $\delta^{15}N$ data and a land surface model

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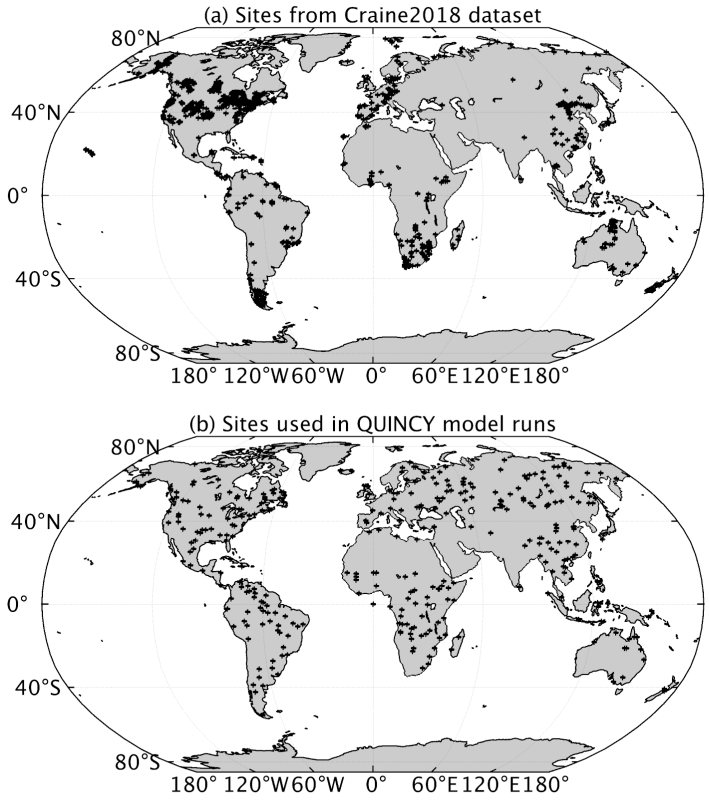

Figure S1 - Geographical distribution of (a) sites from the Craine2018 dataset and (b) sites used for all QUINCY model scenarios.

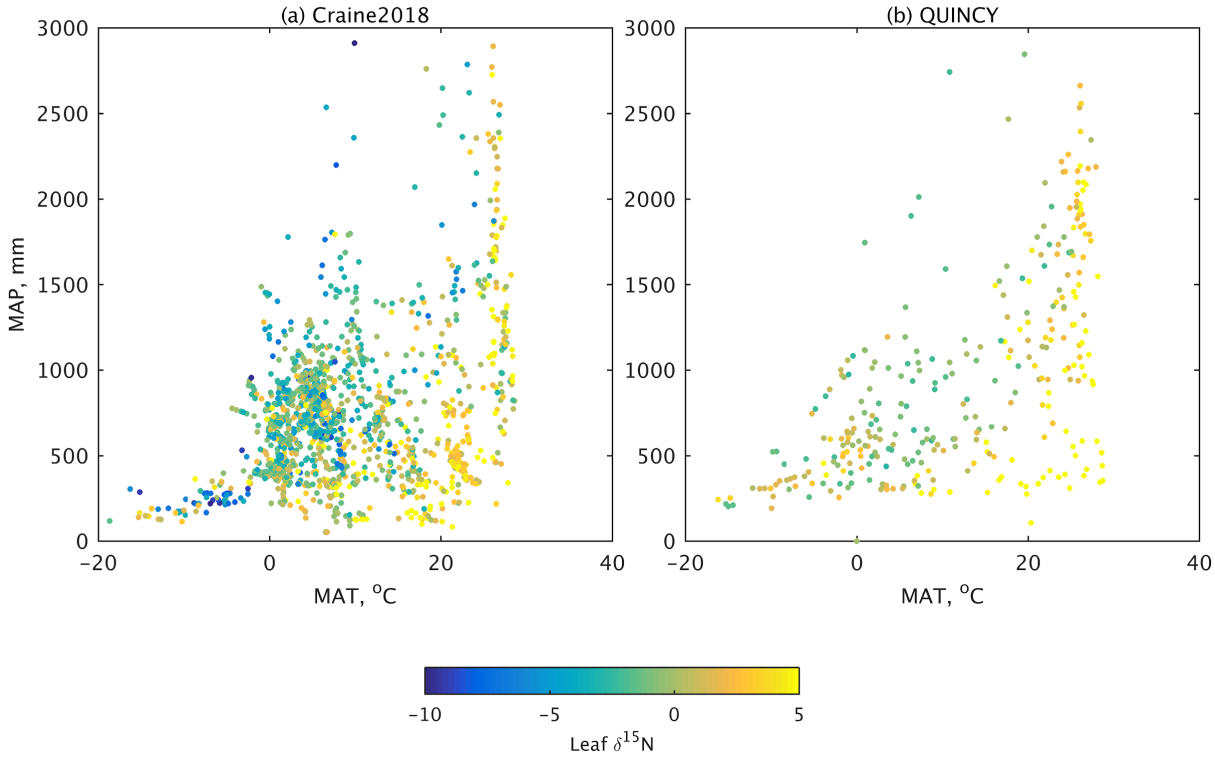

Figure S2 - Distribution of absolute values of leaf $\delta^{15}N$ across climate regions defined by mean annual temperature (MAT) and mean annual precipitation (MAP) for (a) the Craine 2018 dataset and (b) the QUINCY model.

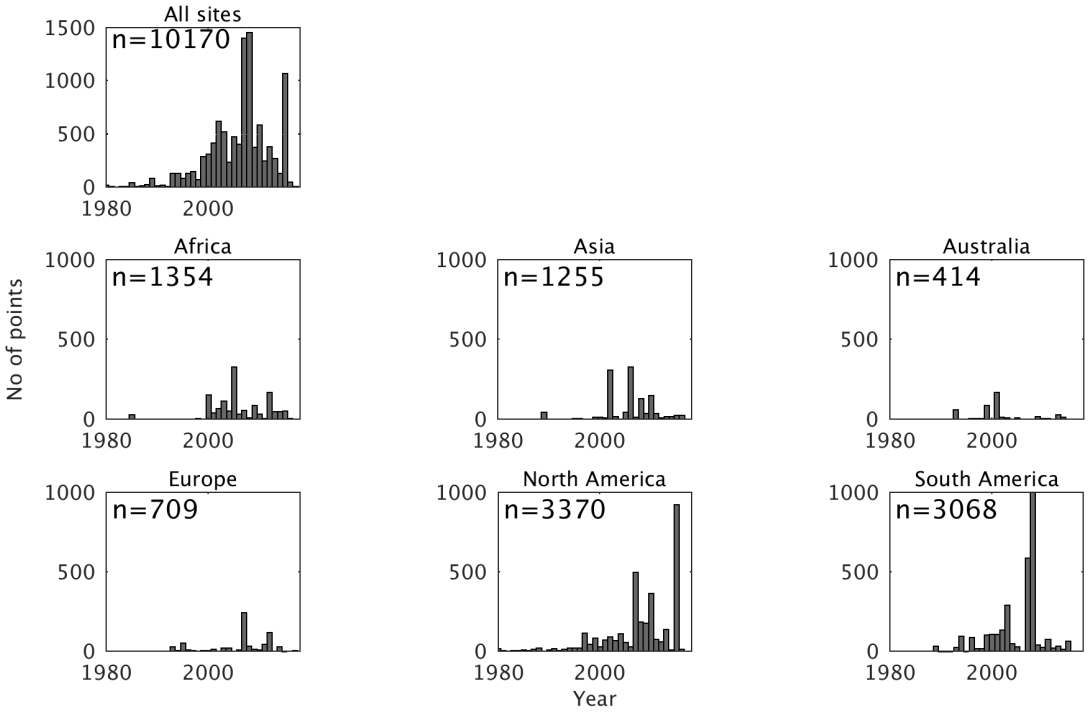

Figure S3 - Temporal distribution of data points in the Craine2018 dataset.

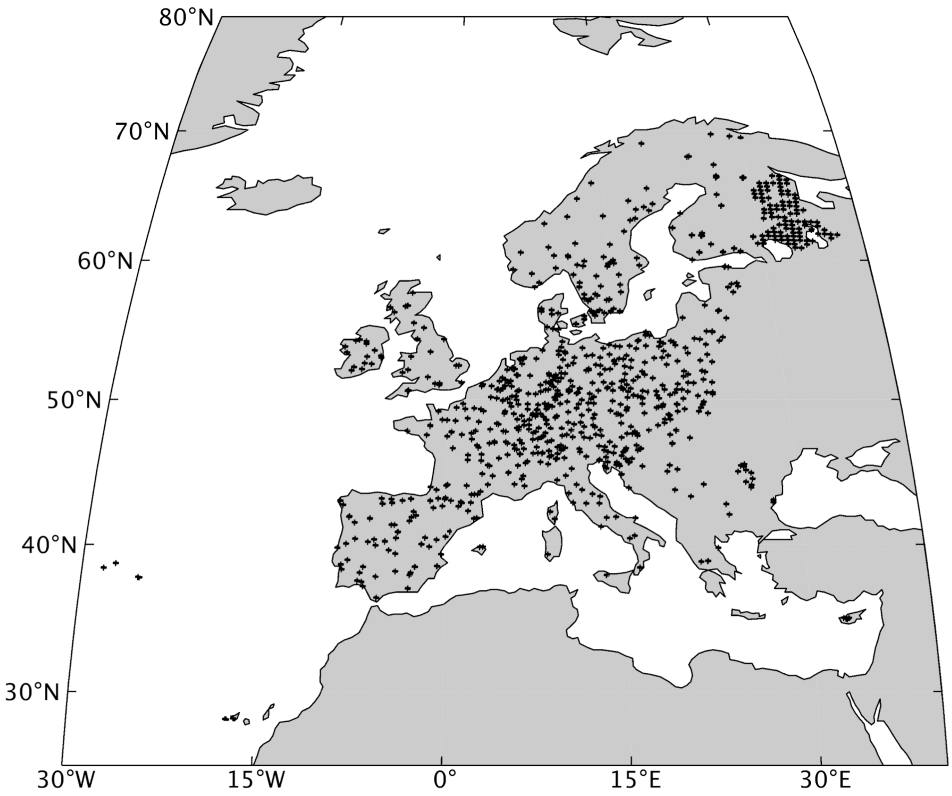

Figure S4 - Geographic distribution of measurement plots in the ICP Forests dataset.

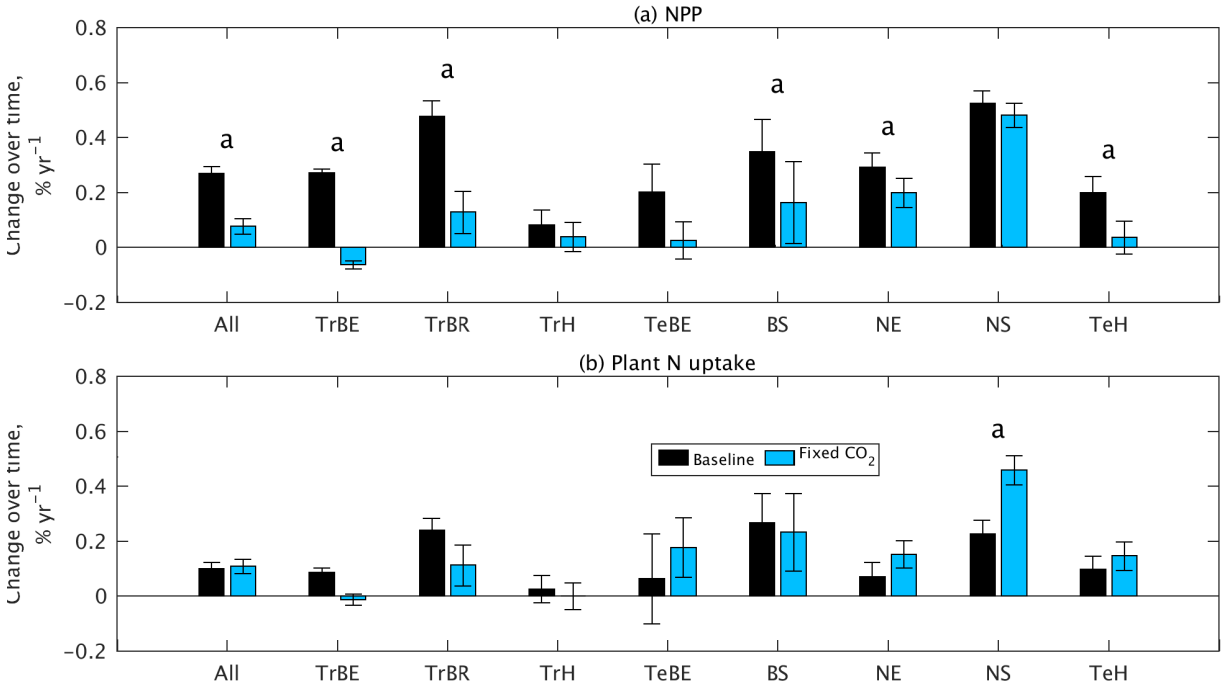

Figure S5 - Plant growth change from 1980-2018 across all PFTs due to the increase in atmospheric CO2 as predicted by the model. Relative change in (a) annual net primary productivity (NPP), (b) plant nitrogen uptake. Error bars represent standard error across sites. PFTs for which the model predicts a significant difference between the baseline and fixed CO_2 runs are indicated with ‘a’; significance computed with Wilcoxon rank sum test at $p<0.05$. PFT abbreviations:TrBE tropical broadleaf evergreen,TrBR tropical broadleaf rain-green,TrH, C4 grassland, TeBE temperate broadleaf evergreen, BS broadleaf seasonal, NE needleleaf evergreen, NS needleleaf seasonal, TeH C3 grassland.

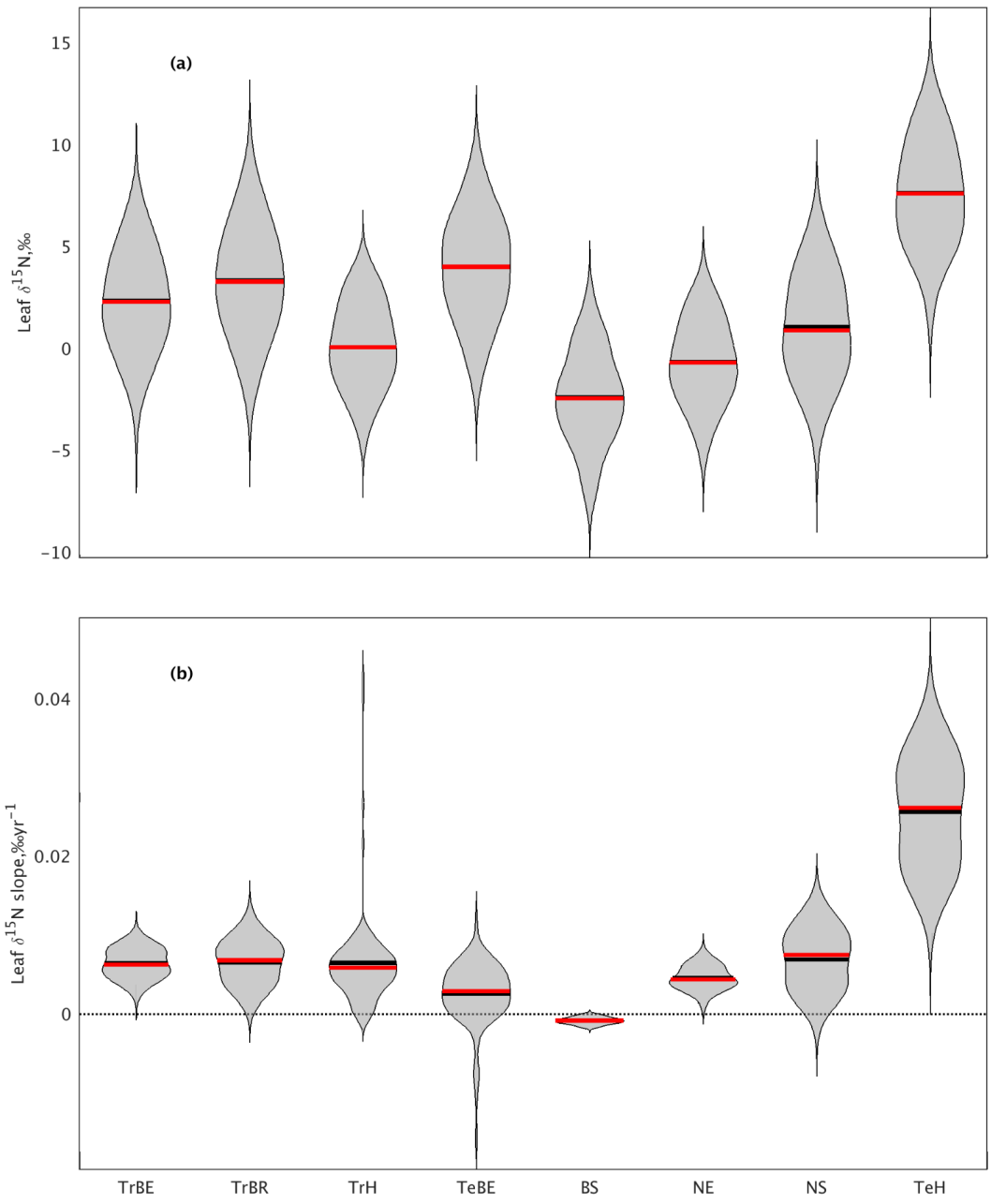

Figure S6 - Parameter sensitivity of (a) mean leaf $\delta^{15}N$ and (b) leaf $\delta^{15}N$ slope over time for one randomly selected site for each PFT. Results from 100 model ensemble runs using Latin hypercube sampling for all N isotope fractionation parameters (Table S2). Note slopes are calculated for each site for each parameter combination using Eqs. 5 and 6, and are therefore not directly comparable in magnitude to slopes in FIgs. 3 and 6. PFT abbreviations:TrBE tropical broadleaf evergreen,TrBR tropical broadleaf rain-green,TrH, C4 grassland, TeBE temperate broadleaf evergreen, BS broadleaf seasonal, NE needleleaf evergreen, NS needleleaf seasonal, TeHe C3 grassland.

Table S1 - Plant functional type (PFT) used in the QUINCY model

Abbreviation	Description
TrBE	Tropical broadleaf evergreen
TrBR	(Tropical)broadleaf rain deciduous
TeBE	Temperate broadleaf evergreen
BS	(Temperate and boreal) broadleaf winter deciduous
NE	(Temperate and boreal) needleleaf evergreen
NS	(Temperate and boreal) needleleaf winter deciduous
TeH	C3 grass
TrH	C4 grass

Table S2 - Nitrogen isotopic fractionation (ε) values in QUINCY, as described in (Thum *et al.*, 2019) adapted from (Robinson, 2001)

Process	Value, ‰
Microbial NH_4 uptake	17.0
Plant NH_4 uptake	13,5
Plant NO_4 uptake	9.5
Nitrification	47.5
NO_3 production	25.0
Denitrification	31.0
NH_4 production	2.5
Biological nitrogen fixation	3.0

Table S3 - Number of sites within each PFT for each dataset used and in the QUINCY model sites

PFT	QUINCY	Craine2018	ICP Forests
TrBE	48	3470	-
TrBR	10	1432	-
TeBE	8	364	33
BS	28	1492	324
NE	54	396	613
NS	9	11	4
TeH	74	2273	-
TrH	80	743	-

References

Robinson, D. (2001) ‘δ15N as an integrator of the nitrogen cycle’, *Trends in ecology & evolution*, 16(3), pp. 153–162. doi: 10.1016/S0169-5347(00)02098-X.

Thum, T. *et al.* (2019) ‘A new model of the coupled carbon, nitrogen, and phosphorus cycles in the terrestrial biosphere (QUINCY v1.0; revision 1996)’, *Geoscientific Model Development*, 12(11), pp. 4781–4802. doi: 10.5194/gmd-12-4781-2019.