

New Phytologist Supporting Information

Article title: Empirical evidence and theoretical understanding of ecosystem carbon and nitrogen cycle interactions

Authors: Benjamin D. Stocker, Ning Dong, Evan A. Perkowski, Pascal D. Schneider, Huiying Xu, Hugo de Boer, Karin T. Rebel, Nicholas G. Smith, Kevin Van Sundert, Han Wang, Sarah E. Jones, I. Colin Prentice and Sandy P. Harrison

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Notes S2 Meta-analysis of ecosystem experiments

Notes S2.1 Statistical analysis

The natural logarithm of the response ratio of the means and its variance were calculated for each response variable, experiment, treatment, and sampling year, using information about the the number of repeated measurements (multiple experimental plots, multiple sampling dates per year). This was done using the function `escalc(measure="ROM", ...)` from the `{metafor}` R package (Viechtbauer, 2010). The standard error was calculated as $SE = \sqrt{\text{var}/N}$, where N is the number of repeated measurements.

For CO₂ experiments, the response ratio was normalised with (divided by) the natural logarithm of the ratio of elevated over ambient CO₂ concentrations.

Data was then aggregated by experiment using the procedure based on Borenstein (2009), implemented by the function `agg(method = "BHHR", ...)` from the `{MAd}` R package (Hoyt, 2014), and assuming a correlation of within-study response ratios of 0.5.

Finally, the meta-analysis of responses across experiments was performed as a mixed-effects meta-regression model using experiment as the grouping variable for random factors, and fitted via the restricted maximum likelihood estimation. This is implemented using the function `rma.mv(method = "REML", ...)` from the `{metafor}` R package (Viechtbauer, 2010). The confidence intervals (edges of boxes in Fig. 3) of the meta-analytic mean response ratio (bold line inside boxes in Fig. 3) span 95%.

Notes S2.2 Response to CO₂, MESI data

Notes S2.2.1 Data selection

Data were used from the Manipulation Experiments Synthesis Initiative (MESI) database (Van Sundert et al., 2023), obtained from GitHub (<https://github.com/MESI-organization/mesi-db>). For CO₂ experiments, we considered only data from Free Air CO₂ Enrichment (FACE) experiments and from open-top chamber experiments, from experiments that provided data from at least three years. For data generated in multi-factorial experiments, we used only data from the CO₂-only treatment (no interactions with other experimentally manipulated factors considered). Variables shown in this manuscript (Fig. 3, 4, and 6 in this study) were identified by the response variable name in the database according to Tab. 1.

Notes S2.2.2 Extended results

Table 1: Variables in the MESI database used for the analysis.

| Variable name | Variable code | Variable names in MESI |
|-------------------|------------------|--|
| AGB | agb | agb_coarse, agb |
| BGB | bgb | bgb, fine_root_biomass, coarse_root_c_stock, bgb_coarse |
| LAI | lai | lai, lai_max |
| Root NPP | root_production | root_production, fine_root_production, coarse_root_production |
| N uptake | n_uptake | root_n_uptake, root_nh4_uptake, root_no3_uptake |
| Inorganic N | n_inorg | soil_no3-n, soil_nh4-n, soil_nh4, soil_no3, soil_solution_nh4, soil_solution_no3 |
| A_{sat} | asat | asat |
| V_{cmax} | vcmax | vcmax |
| J_{max} | jmax | jmax |
| GPP | gpp | gpp |
| N_{area} | leaf_n_area | leaf_n_area |
| N_{mass} | leaf_n_mass | leaf_n_mass |
| Leaf C:N | leaf_cn | leaf_cn |
| ANPP | anpp | anpp |
| Root:shoot | root_shoot_ratio | root_shoot_ratio |

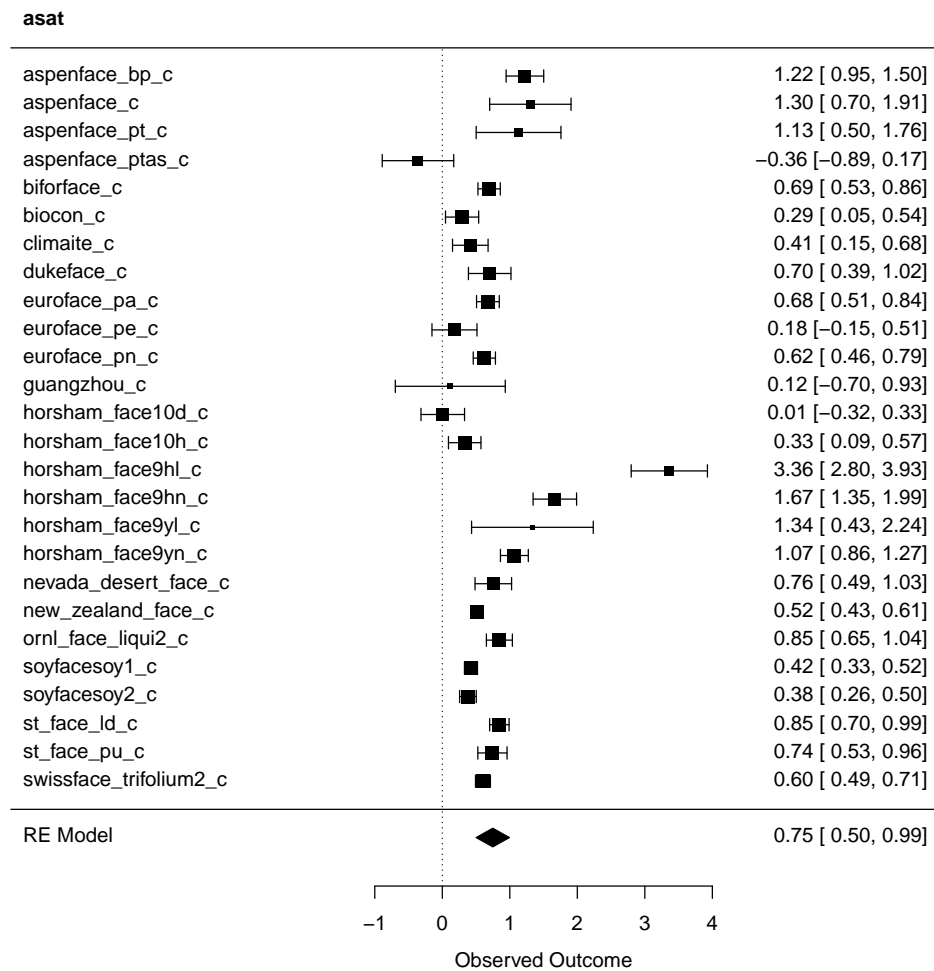


Figure 1: Response of leaf-level assimilation under light-saturated conditions (A_{sat}) to elevated CO_2 in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

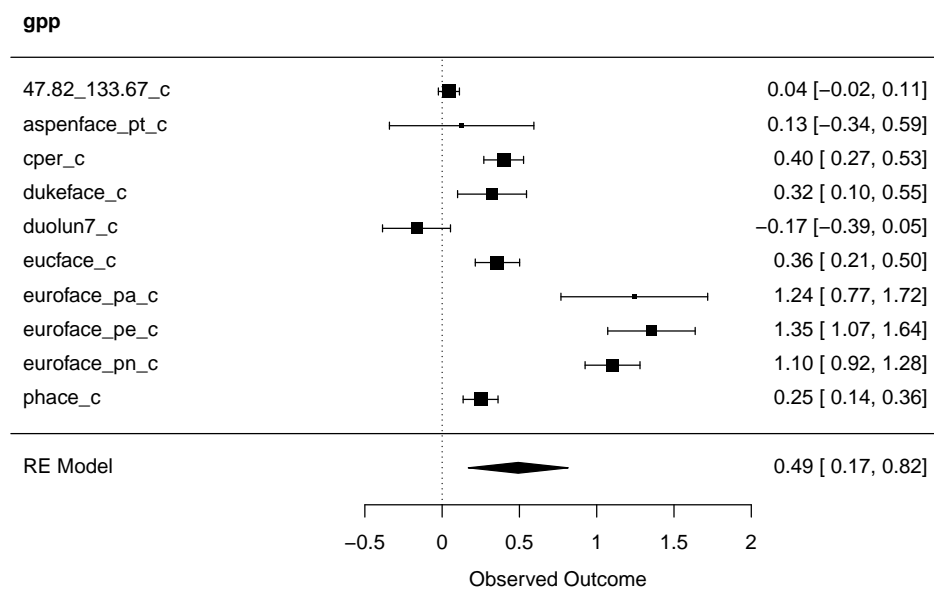


Figure 2: Response of GPP to elevated CO₂ in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

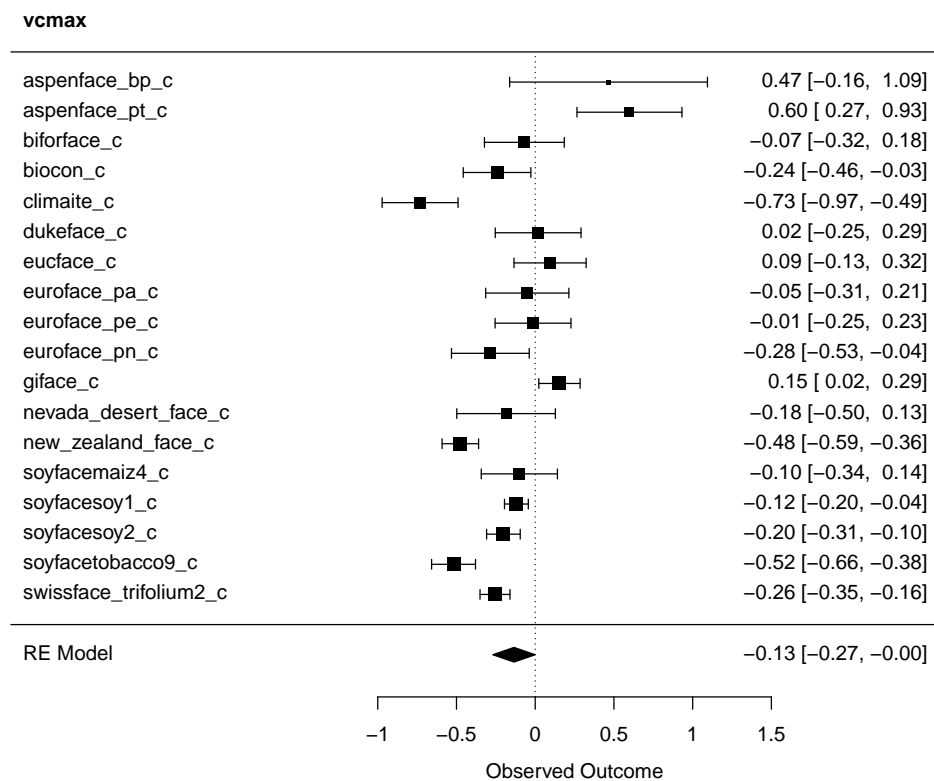


Figure 3: Response of V_{cmax} to elevated CO_2 in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

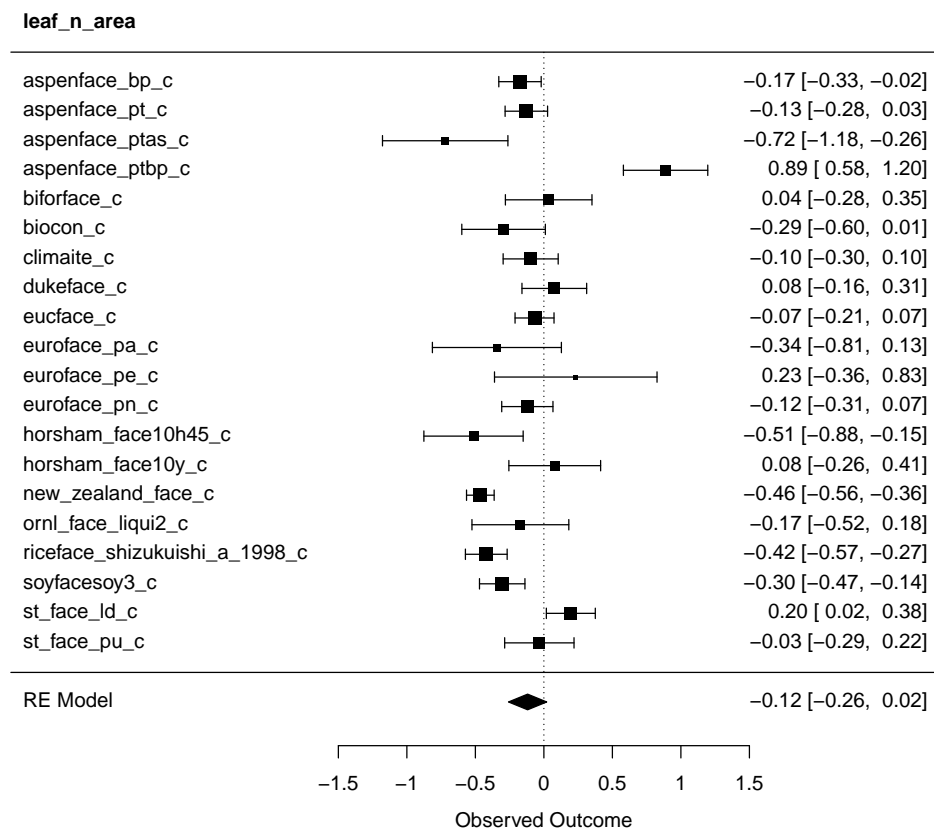


Figure 4: Response of leaf N_{area} to elevated CO_2 in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

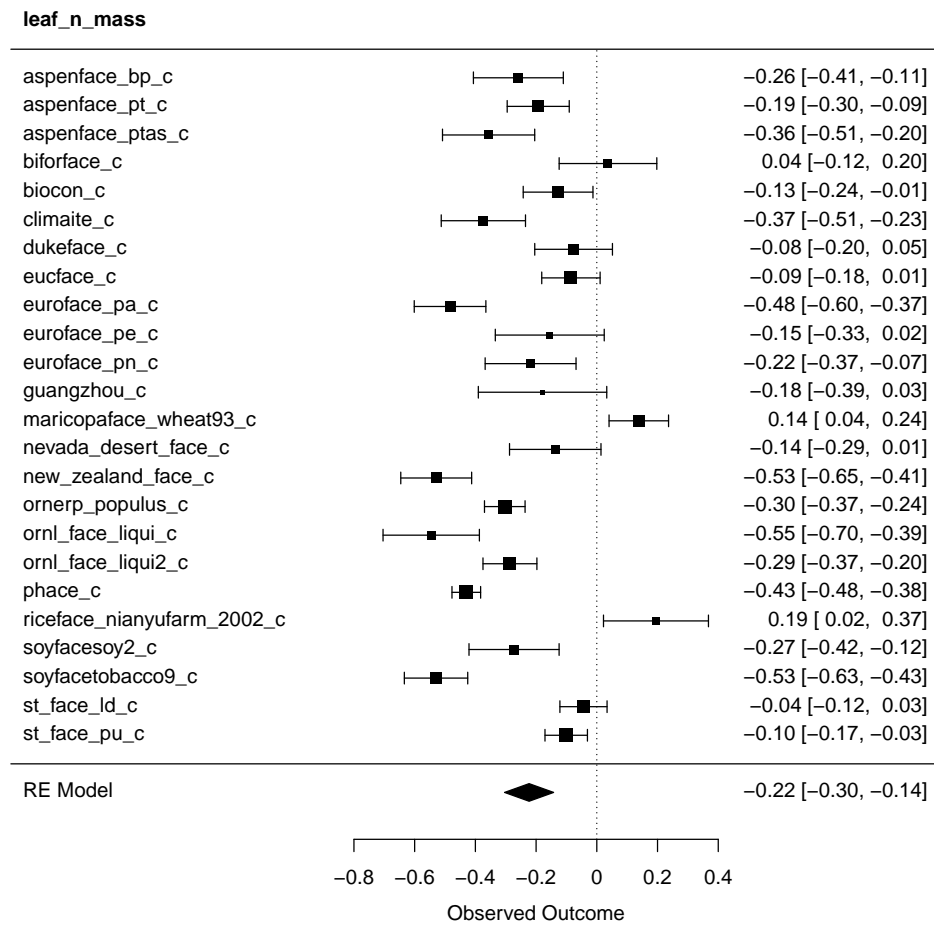


Figure 5: Response of leaf N_{mass} to elevated CO_2 in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

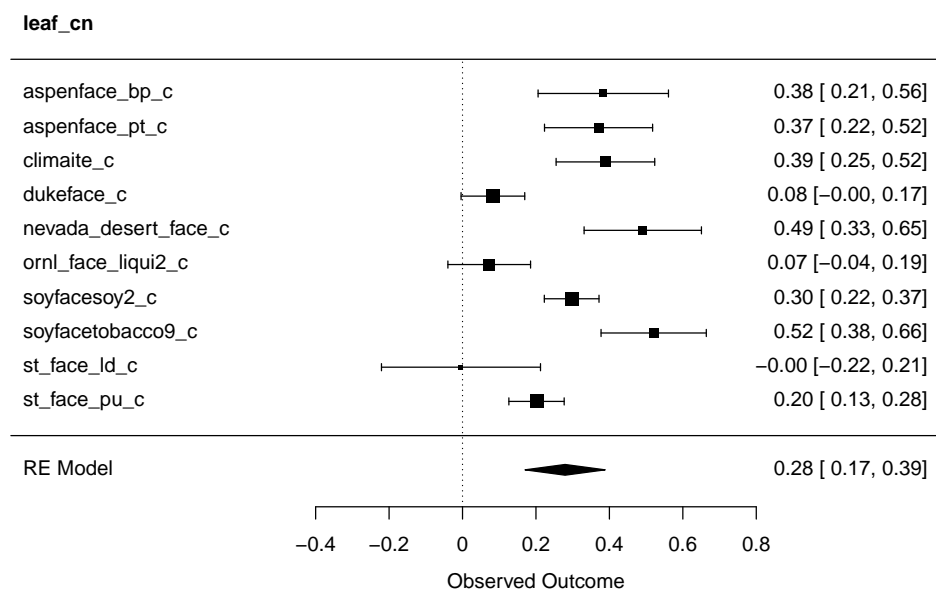


Figure 6: Response of leaf C:N to elevated CO₂ in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

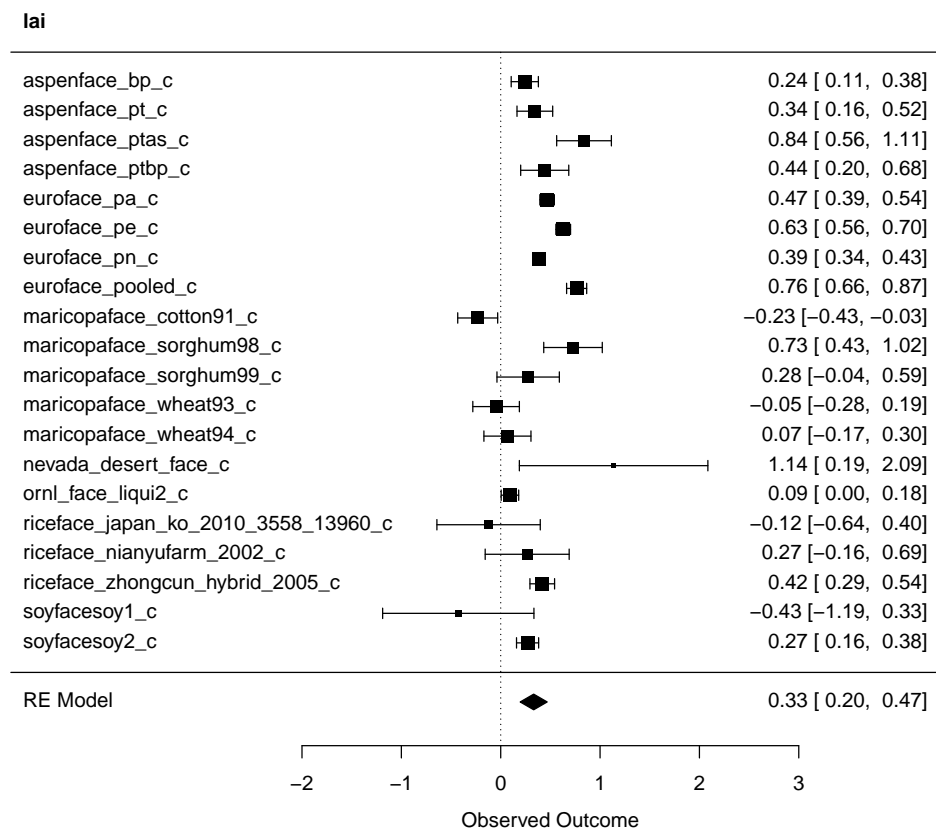


Figure 7: Response of LAI to elevated CO₂ in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

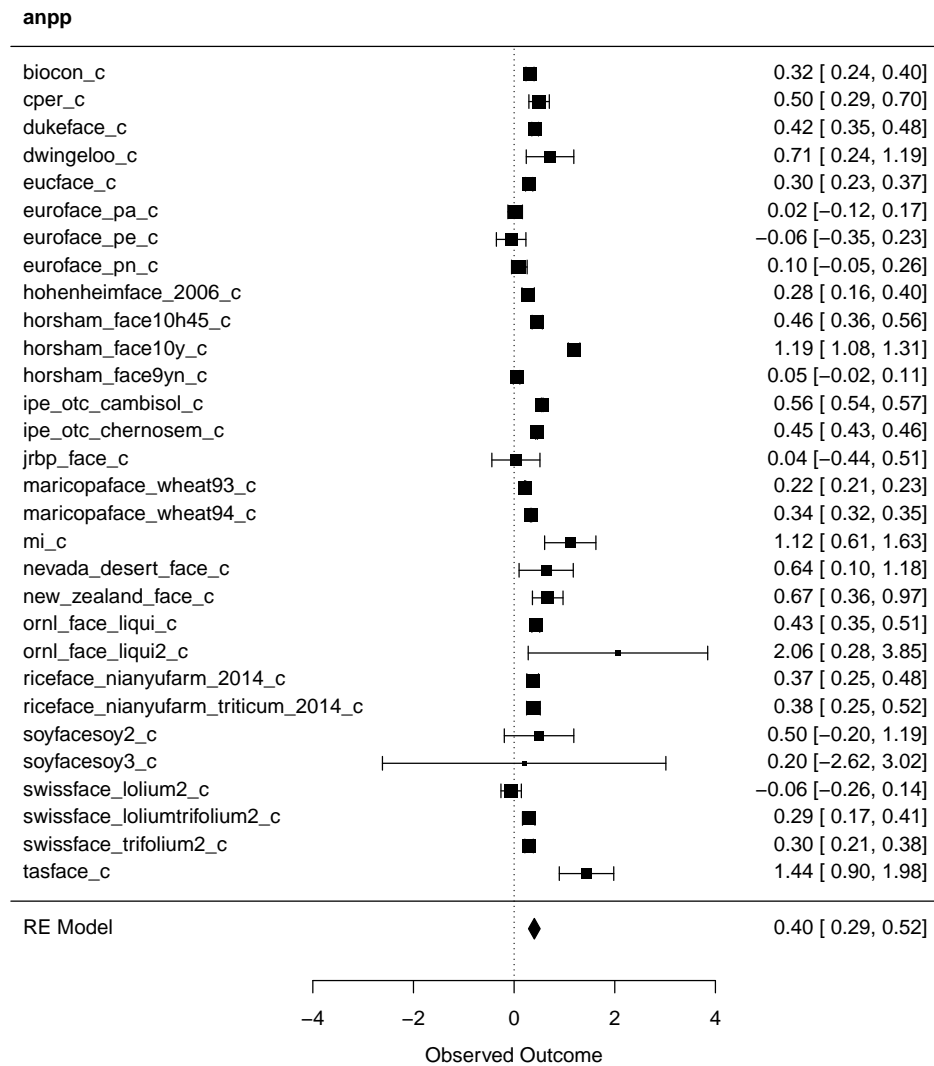


Figure 8: Response of aboveground net primary productivity (ANPP) to elevated CO_2 in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

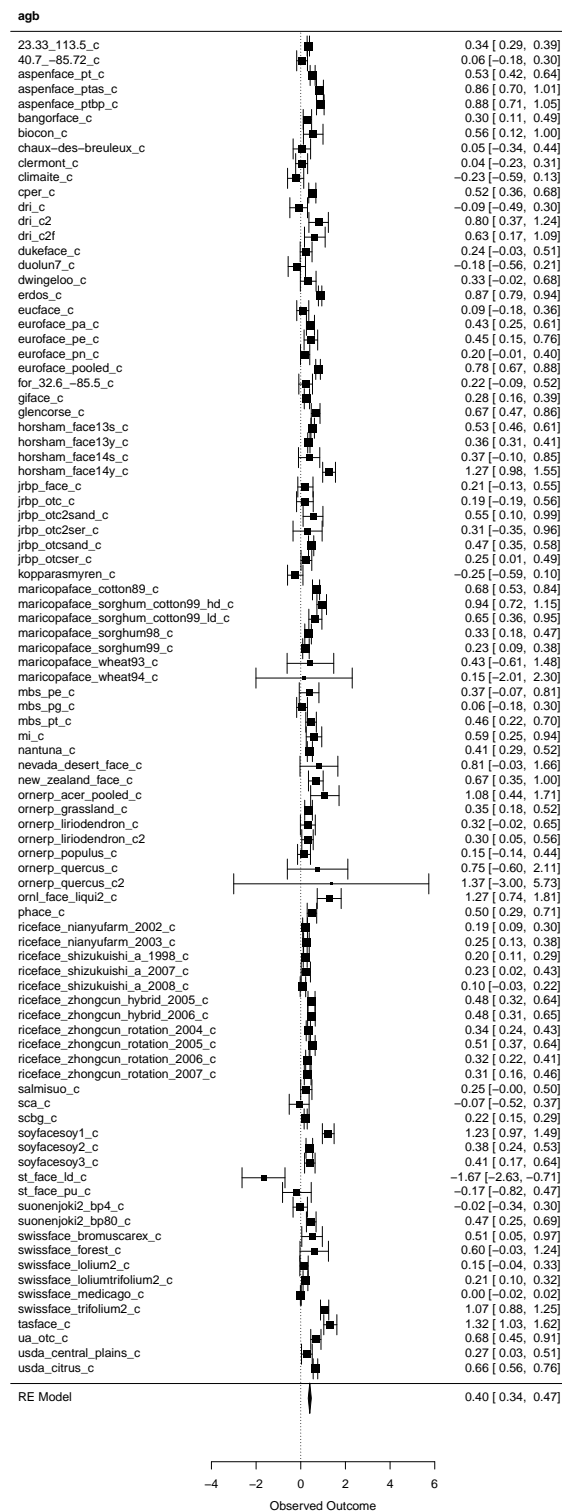


Figure 9: Response of aboveground biomass (AGB) to elevated CO₂ in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

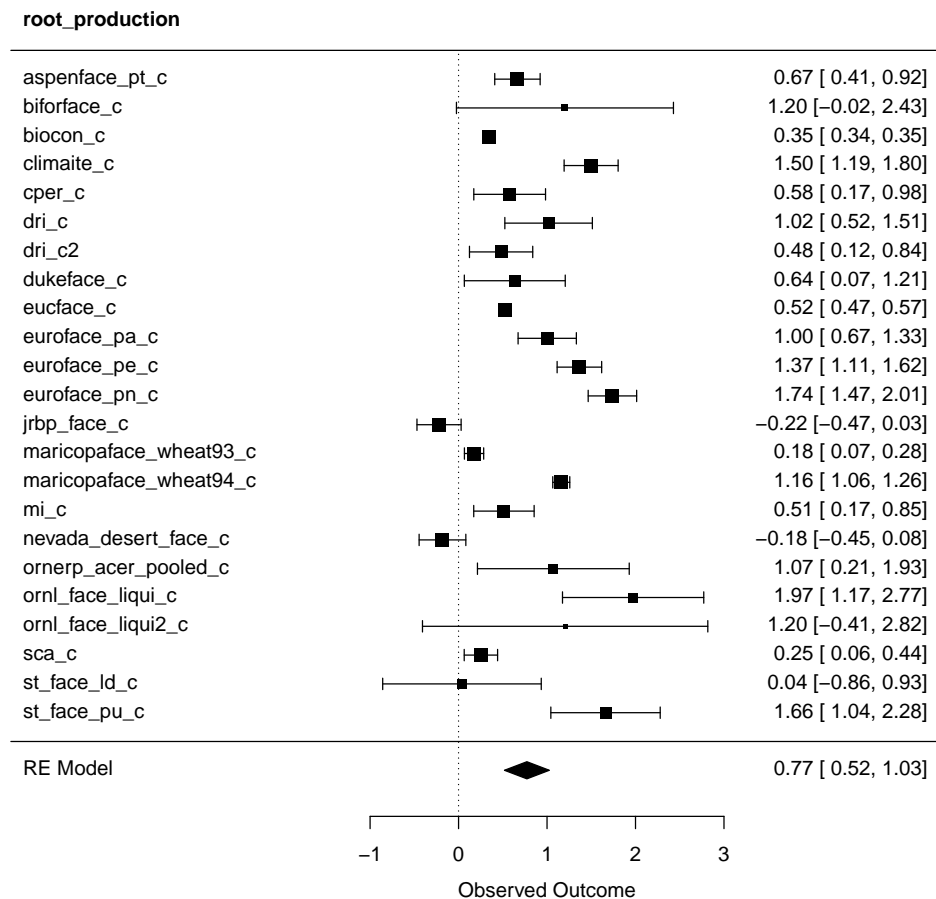


Figure 10: Response of root biomass productivity to elevated CO₂ in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

Notes S2.3 Response to N-fertilisation, MESI and NutNet data

Notes S2.3.1 Data selection

Data were used from the Manipulation Experiments Synthesis Initiative (MESI) database (Van Sundert et al., 2023), obtained from GitHub (<https://github.com/MESI-organization/mesi-db>). For variables belowground biomass (bgb, `Rootsgperm2` in NutNet), root mass fraction (rmf, `rootmassfraction` in NutNet), aboveground biomass (agb), and the root:shoot ratio (`root_shoot_ratio`), we combined MESI data with data from the meta-analysis of the NutNet experiments network by Cleland et al. (2019). Aboveground biomass from NutNet data was calculated as $(\text{bgb}/\text{rmf}) - \text{bgb}$. The root:shoot ratio from NutNet data was calculated as bgb/agb .

For MESI data, only data from field experiments were used for which the N application rate was less or equal to $300 \text{ kg N ha}^{-1} \text{ yr}^{-1}$. For data generated in multifactorial experiments, we used only data from the N-fertilisation-only treatment (no interactions with other experimentally manipulated factors considered). Variables shown in this manuscript (Fig. 3, 4, and 6 in this study) were identified by the response variable name in the database according to Tab. 1.

Notes S2.3.2 Extended results

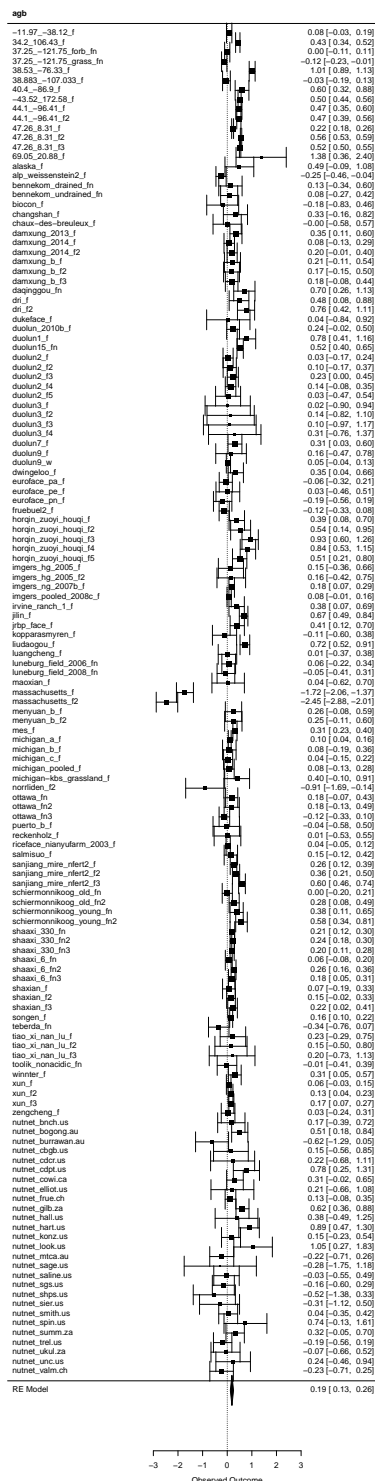


Figure 11: Response of aboveground biomass (agb) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the {metafor} R package Viechtbauer (2010).

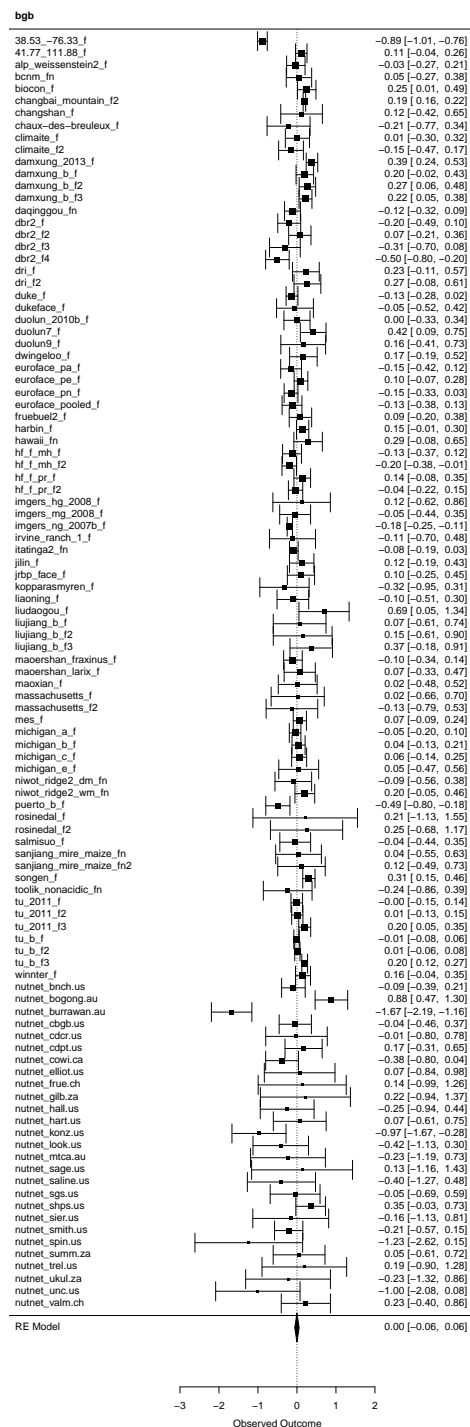


Figure 12: Response of belowground biomass (bgb) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

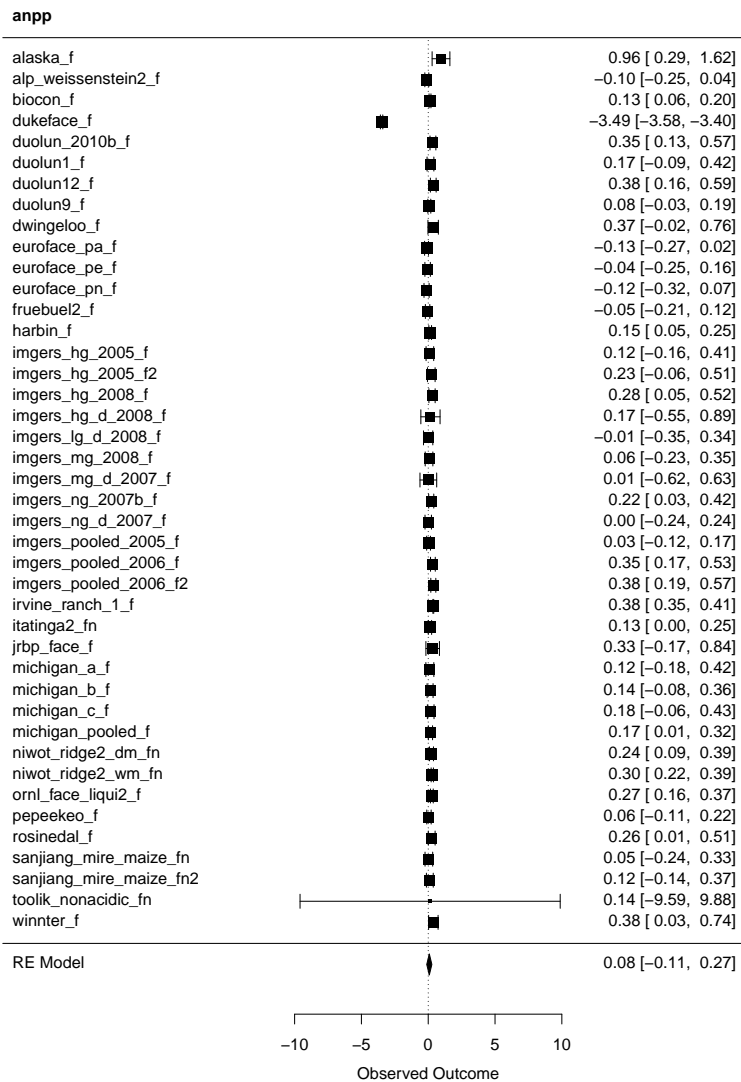


Figure 13: Response of aboveground net primary production (anpp) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

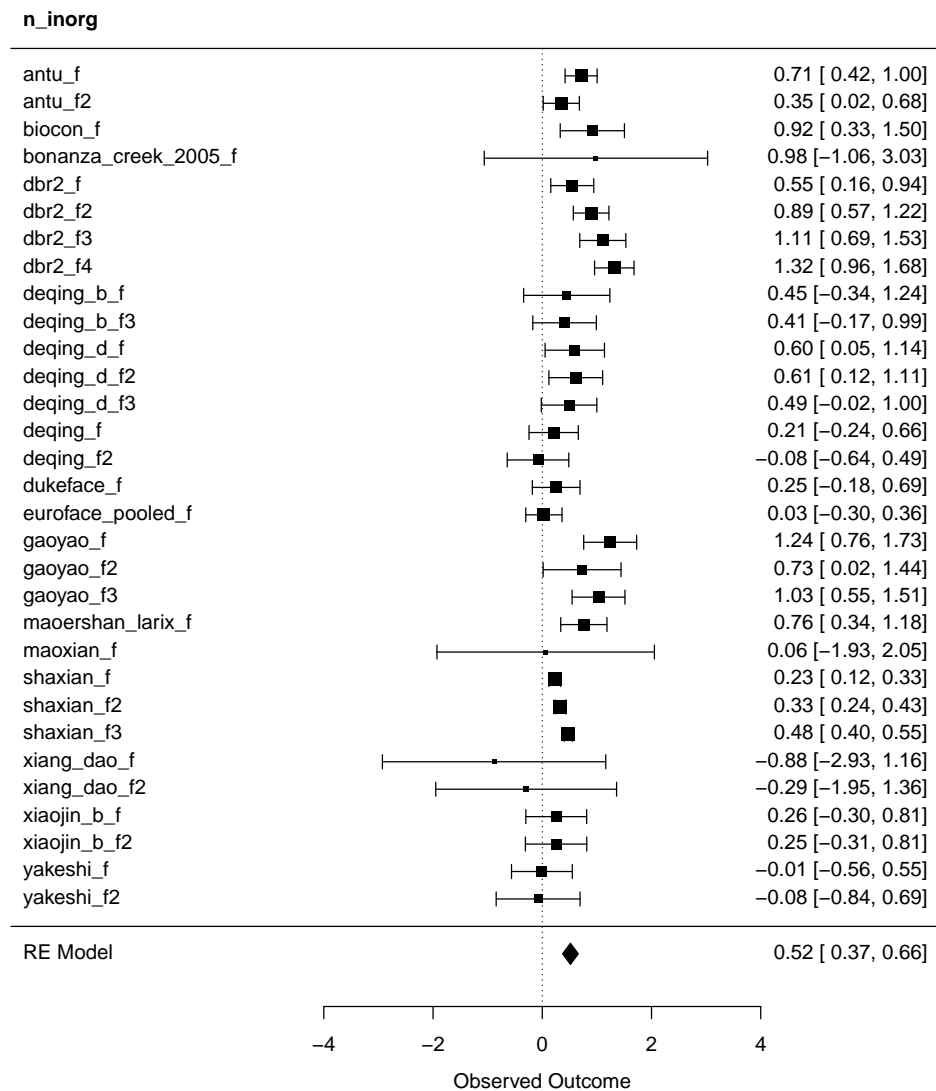


Figure 14: Response of soil inorganic nitrogen (n_inorg) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

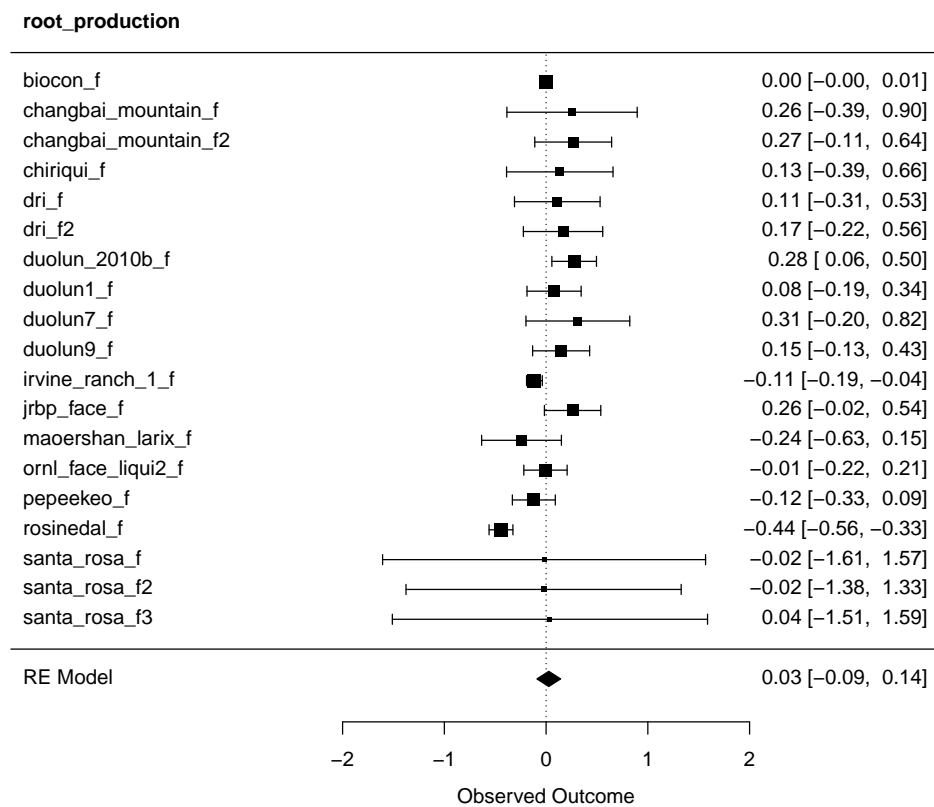


Figure 15: Response of root biomass production (root_production) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

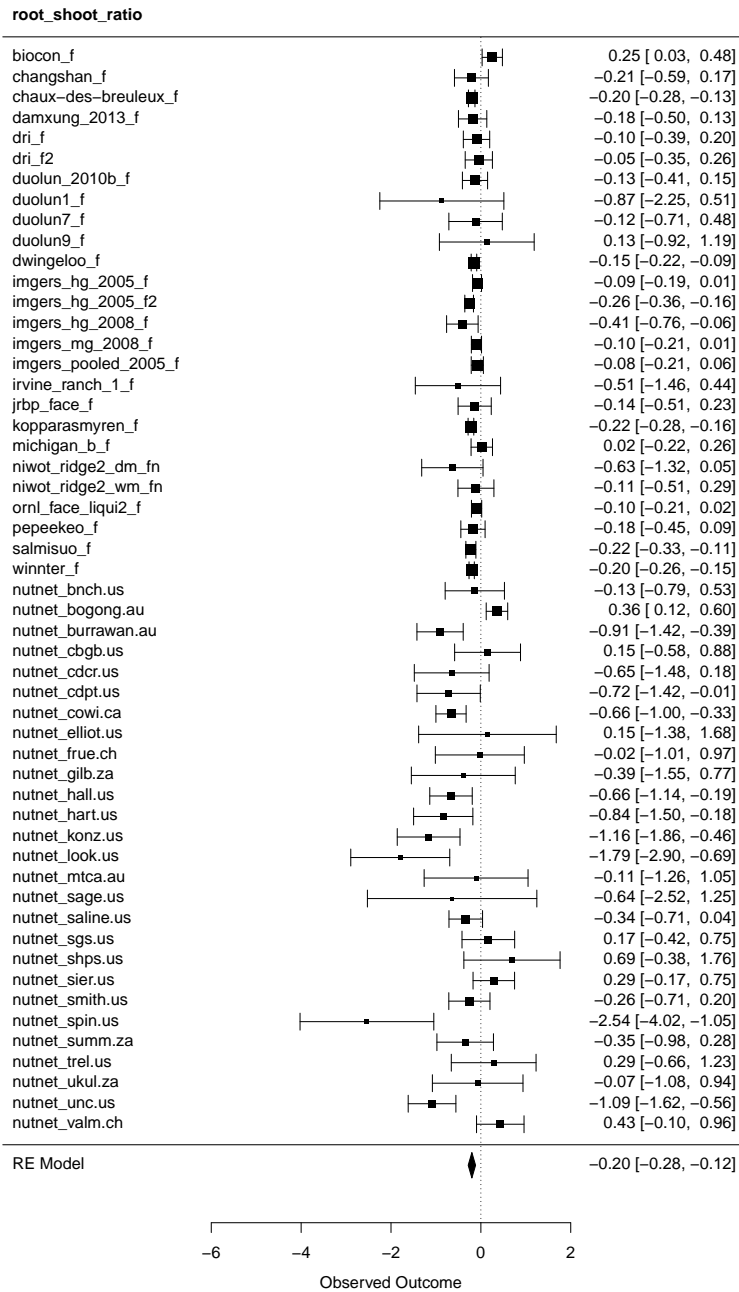


Figure 16: Response of the root:shoot ratio (root.shoot_ratio) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

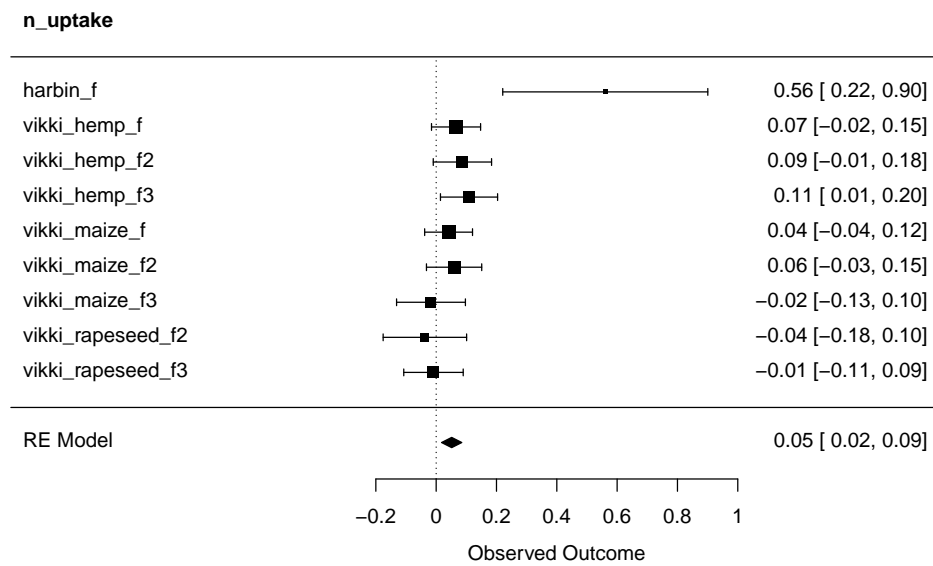


Figure 17: Response of the N uptake ratio (*n_uptake*) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

Notes S2.4 Response to N-fertilisation, Liang et al. data**Notes S2.4.1 Data selection**

Data were used from the meta-analysis by Liang et al. (2020) for which the N application rate was less or equal to $300 \text{ kg N ha}^{-1} \text{ yr}^{-1}$.

Notes S2.4.2 Extended results

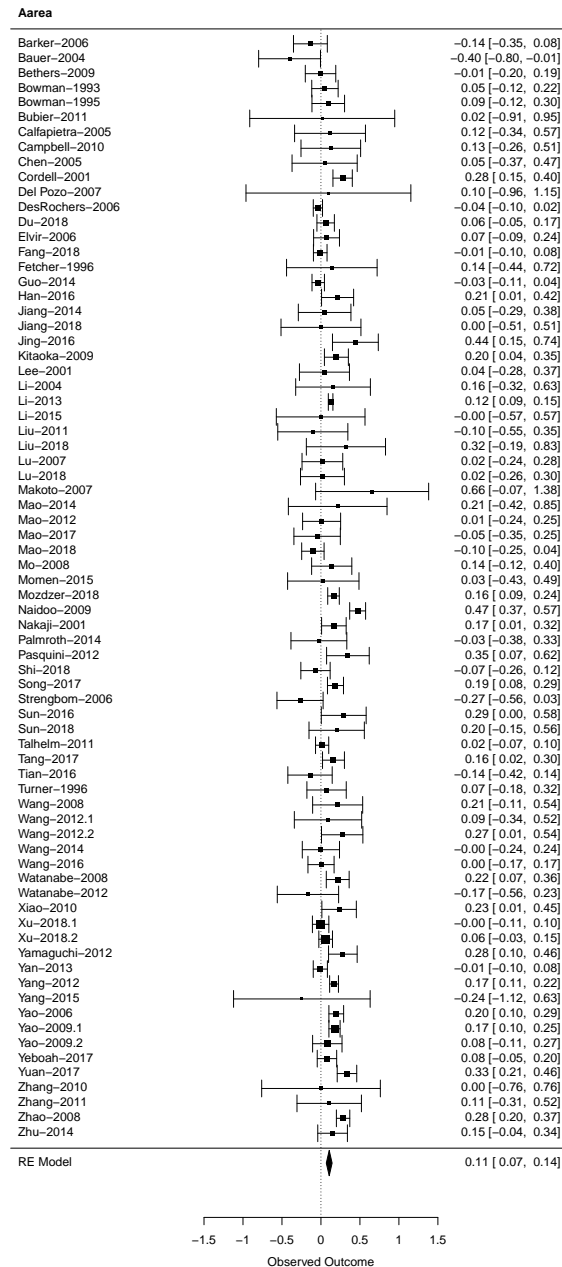


Figure 18: Response of leaf-level assimilation rate (Aarea), here interpreted as representative for light-saturated conditions, to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

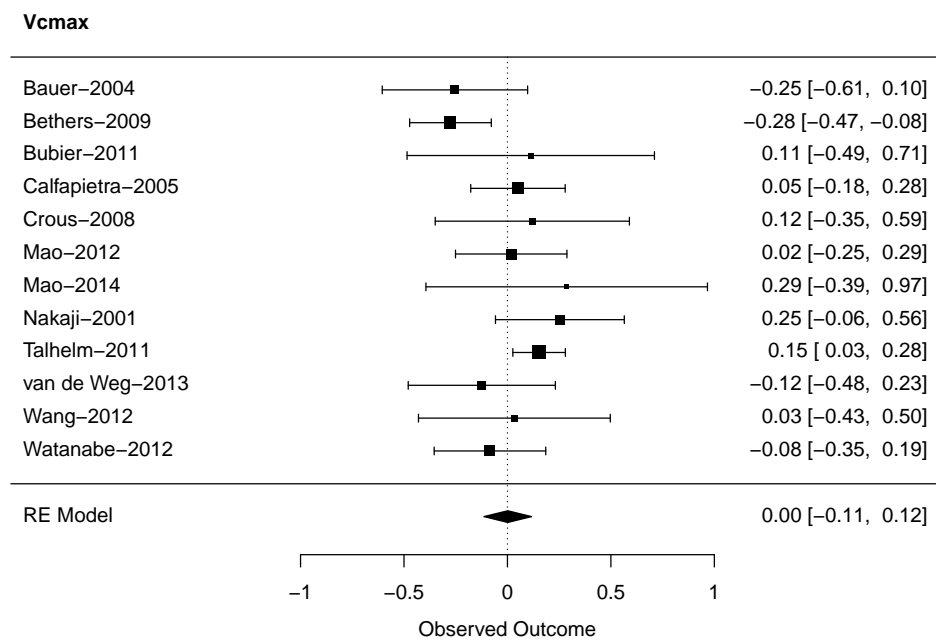


Figure 19: Response of V_{cmax} to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

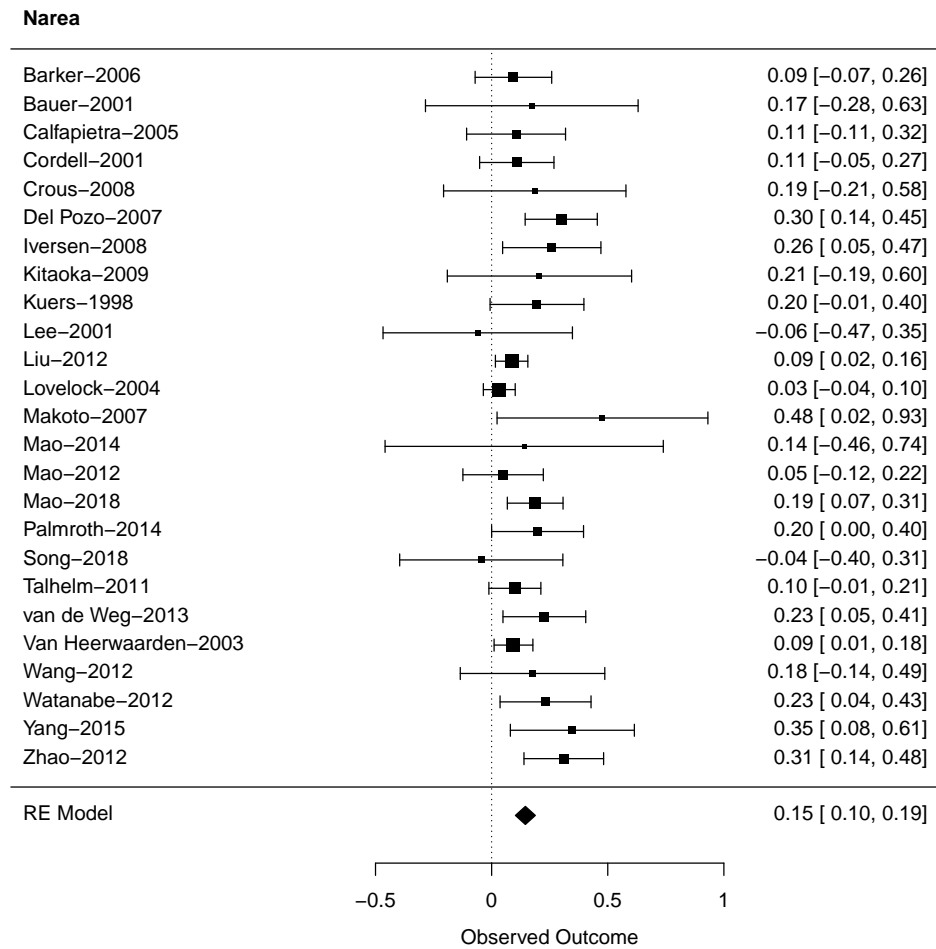


Figure 20: Response of N_{area} (Narea) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

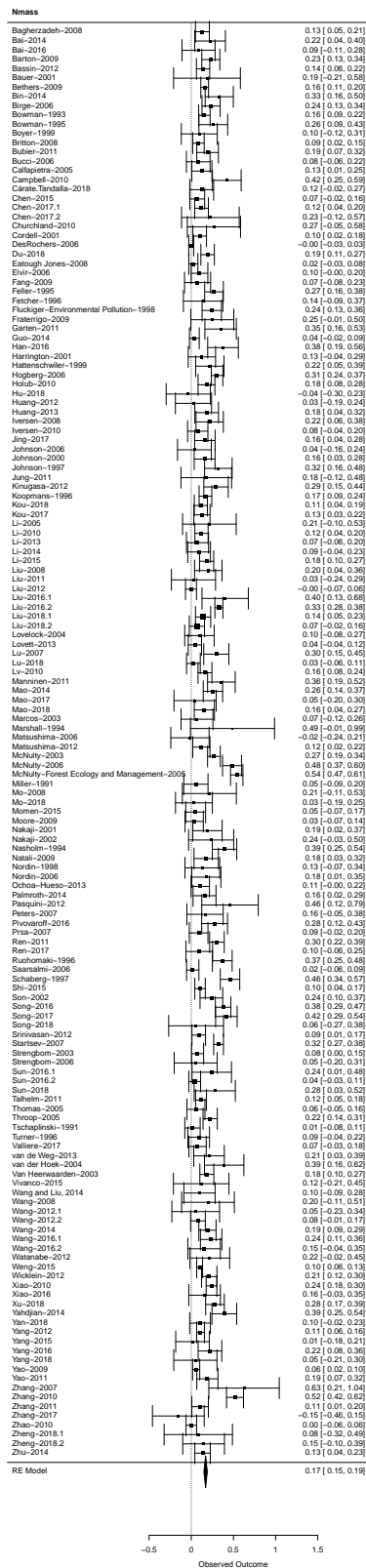


Figure 21: Response of N_{mass} (Nmass) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

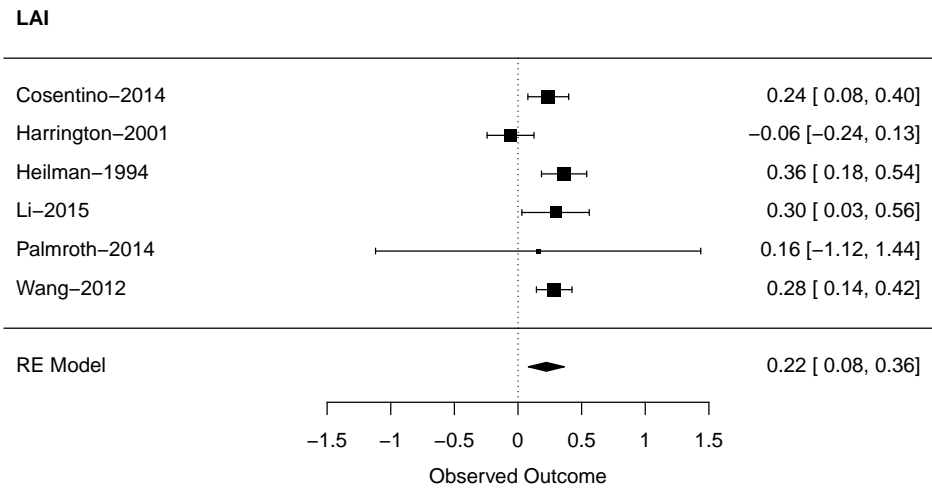


Figure 22: Response of the leaf area index (LAI) to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

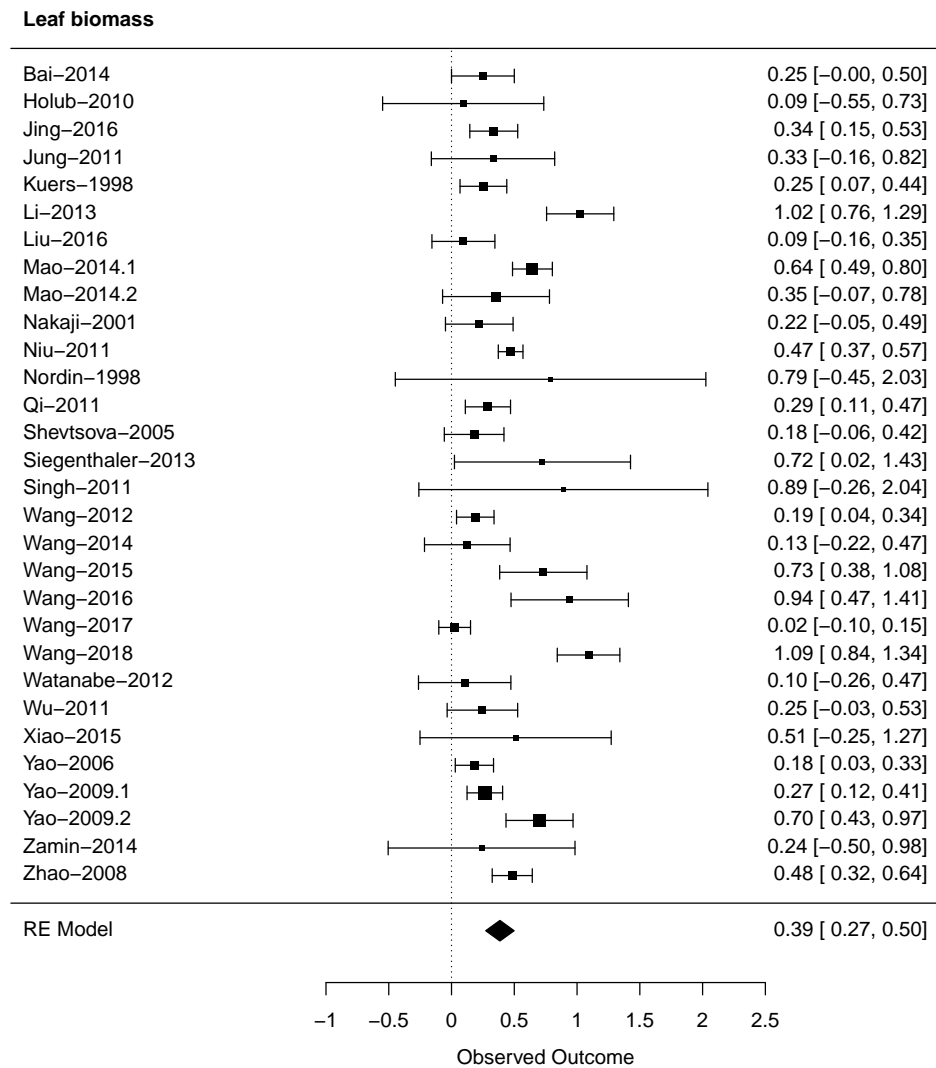


Figure 23: Response of leaf biomass to N-fertilisation in individual experiments and meta-analytic mean across experiments. Plot created with `forest` from the `{metafor}` R package Viechtbauer (2010).

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