

Supplement of Biogeosciences Discuss., 12, 16953–16977, 2015
<http://www.biogeosciences-discuss.net/12/16953/2015/>
doi:10.5194/bgd-12-16953-2015-supplement
© Author(s) 2015. CC Attribution 3.0 License.



Supplement of

Processes regulating progressive nitrogen limitation under elevated carbon dioxide: a meta-analysis

J. Liang et al.

Correspondence to: J. Liang (jliang@ou.edu) and Y. Luo (yluo@ou.edu)

The copyright of individual parts of the supplement might differ from the CC-BY 3.0 licence.

Supporting Information

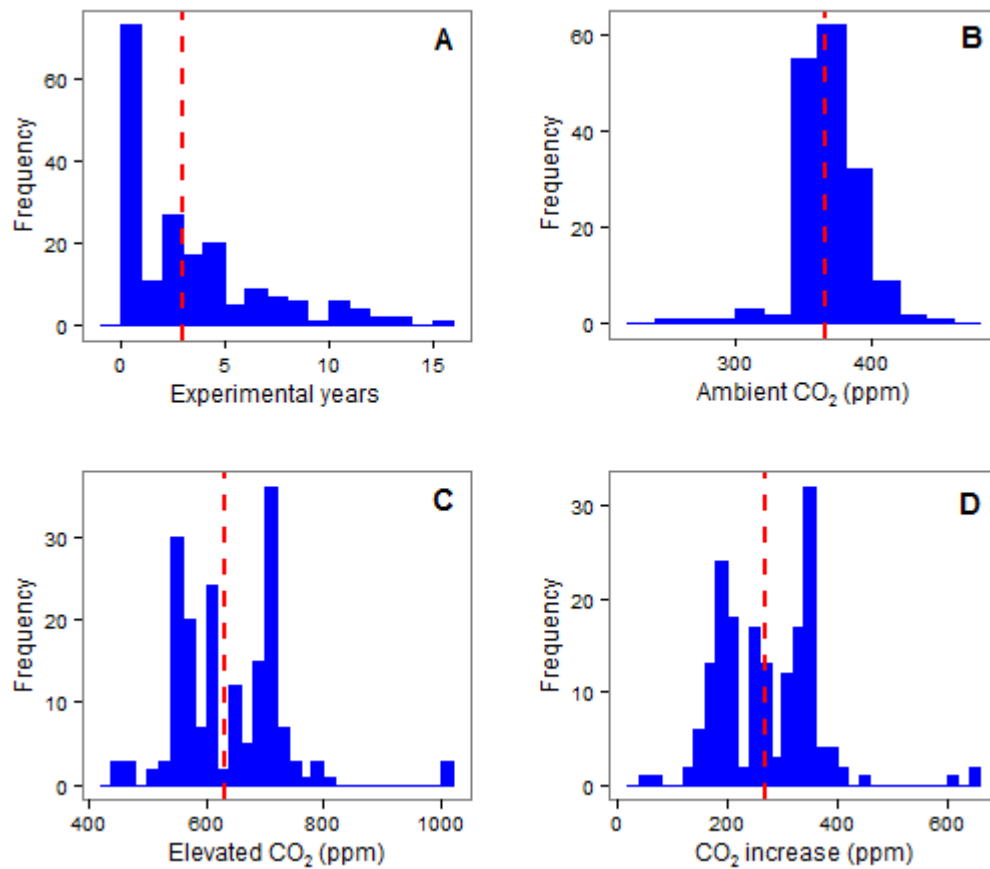


Fig. S1. Distributions of the experimental duration (A) and the CO₂ concentrations under ambient (B) and elevated (C) treatments and their difference (D) for the 175 collected studies. Red dashed lines represent the mean values.

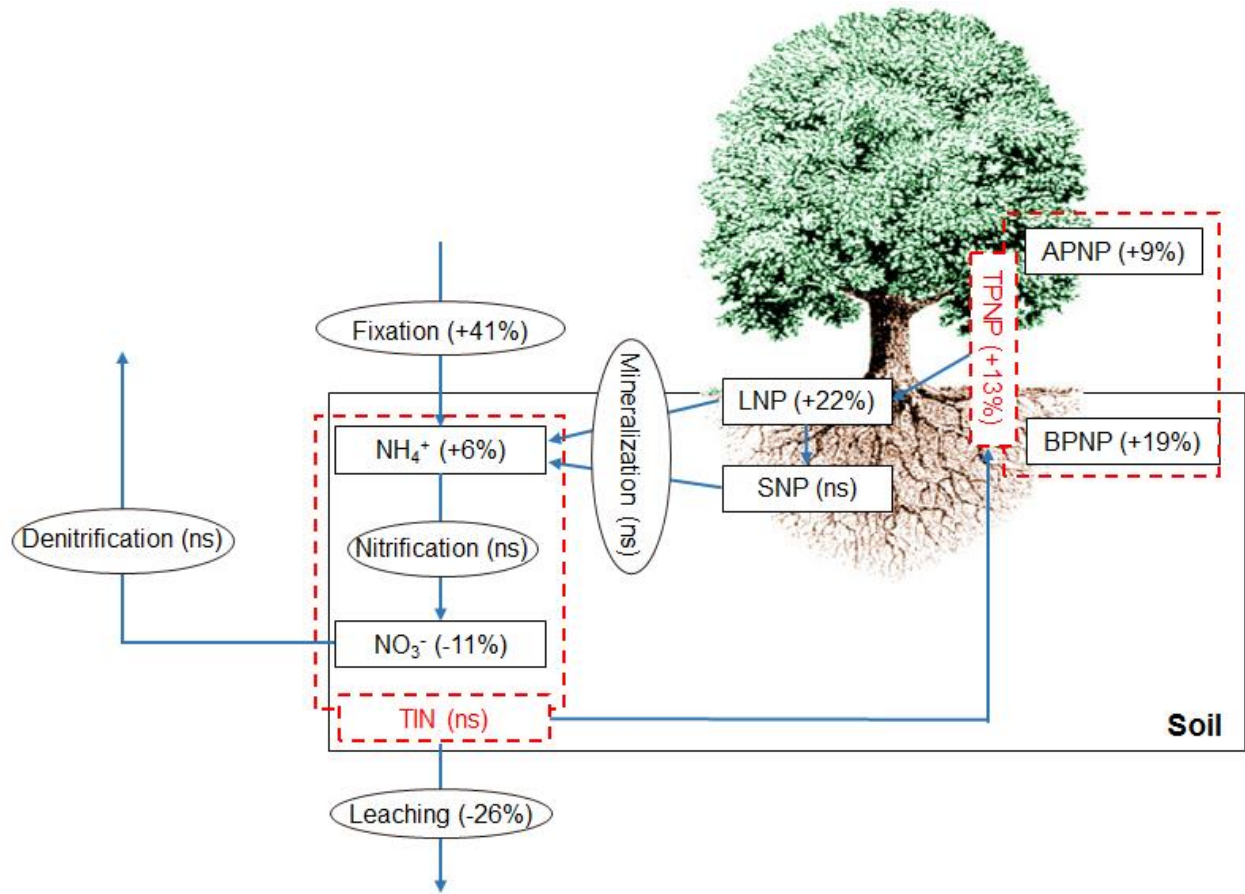


Fig. S2. Summary of the effect of CO₂ enrichment on ecosystem level N budget. Square boxes are nitrogen pools, ovals are nitrogen processes. Red dashed boxes mean the sum of the pools in the boxes. “+”, “-”, and “ns” mean the response to CO₂ enrichment are positive, negative, and not significant, respectively. Please see **Figure 1** for abbreviations.

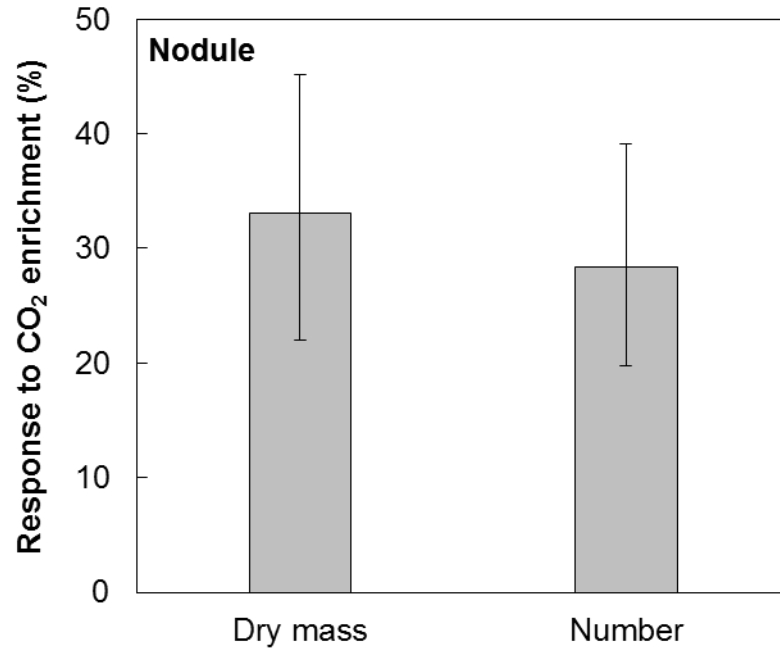


Fig. S3. Responses of the nodule biomass and number in legume plants to CO₂ enrichment (Mean \pm 95% confidence interval).

Table S1 Variables extracted from each paper listed in References S1. Experiment duration (in years) and number of replicates (N_R) are also shown.

Reference	Time (yrs)	N_R	TIN	NH_4^+	NO_3^-	APNP	BPNP	TPNP	LNP	SNP	Fixation	Nodule mass	Nodule number	Net Mineralization	Nitri-fication	Denitri-fication	N_2O emission	Leaching
Allen et al. 2000	2.00	3												×				
Ambus & Robertson 1999	2.00	5	×															×
Andresen et al 2010	2.00	6		×				×										
Aranjuelo et al 2005	0.16	4						×				×						
Aranjuelo et al. 2011	0.58	8				×	×	×										
Arnone 1997	2.00	12	×					×						×				
Arnone 1999	3.00	12				×					×							
Arnone & Bohlen 1998	2.00	12																×
Arnone & Gordon 1990	0.13	5				×	×	×			×	×						
Azam et al. 2013	1.00	5					×											
Bader et al. 2009	6.00	12					×											
Baggs & Blum 2004	10.00	3													×			×
Baggs et al. 2003	8.00	3	×	×	×													×
Barnard et al. 2004 (GCB)	4.00	6	×	×	×													
Barnard et al. 2004 (NP)	1.25	6	×	×	×	×	×	×										
Baslam et al. 2012	0.17	3									×	×						
Berntson & Bazzaz 1997	2.00	6		×				×						×				
Berntson & Bazzaz 1998	2.00	3		×				×						×				
Billes et al. 1993	0.08	4	×			×	×	×						×				
Billings et al. 2002	4.00	3																×
Billings et al. 2003	4.00	3									×							
Billings et al. 2004	4.00	3	×											×				
Blank & Derner 2004	0.25	6	×			×								×				
Bloor et al. 2009	0.33	6	×			×	×	×										
Bradford et al. 2012	0.50	6				×	×	×										
Brown et al. 2007	6.00	8					×											
Cabrerizo et al. 2001	0.08	8							×		×	×						
Calfapietra et al. 2007	3.00	3				×	×	×	×					×	×			
Cantarel et al. 2011	4.00	5																×
Carnol et al. 2002	4.00	5	×	×	×					×				×		×		×

References S1 Papers from which the first dataset was extracted

- Allen AS, Andrews JA, Finzi AC, Matamala R, Richter DD, Schlesinger WH (2000) Effects of free-air CO₂ enrichment (FACE) on belowground processes in a *Pinus taeda* forest. *Ecological Applications*, **10**, 437-448.
- Ambus P, Robertson GP (1999) Fluxes of CH₄ and N₂O in aspen stands grown under ambient and twice-ambient CO₂. *Plant and Soil*, **209**, 1-8.
- Andresen LC, Michelsen A, Ambus P, Beier C (2010) Belowground heathland responses after 2 years of combined warming, elevated CO₂ and summer drought. *Biogeochemistry*, **101**, 27-42.
- Aranjuelo I, Irigoyen JJ, Perez P, Martinez-Carrasco R, Sanchez-Diaz M (2005) The use of temperature gradient tunnels for studying the combined effect of CO₂, temperature and water availability in N₂ fixing alfalfa plants. *Annals of Applied Biology*, **146**, 51-60.
- Aranjuelo I, Pinto-Marijuan M, Avice JC, Fleck I (2011) Effect of elevated CO₂ on carbon partitioning in young *Quercus ilex* L. during resprouting. *Rapid Communications in Mass Spectrometry*, **25**, 1527-1535.
- Arnone JA (1997) Indices of plant N availability in an alpine grassland under elevated atmospheric CO₂. *Plant and Soil*, **190**, 61-66.
- Arnone JA (1999) Symbiotic N₂ fixation in a high Alpine grassland: effects of four growing seasons of elevated CO₂. *Functional Ecology*, **13**, 383-387.
- Arnone JA, Bohlen PJ (1998) Stimulated N₂O flux from intact grassland monoliths after two growing seasons under elevated atmospheric CO₂. *Oecologia*, **116**, 331-335.
- Arnone JA, Gordon JC (1990) Effect of Nodulation, Nitrogen Fixation and CO₂ Enrichment on the Physiology, Growth and Dry Mass Allocation of Seedlings of *Alnus-Rubra* Bong. *New Phytologist*, **116**, 55-66.
- Azam A, Khan I, Mahmood A, Hameed A (2013) Yield, chemical composition and nutritional quality responses of carrot, radish and turnip to elevated atmospheric carbon dioxide. *Journal of the Science of Food and Agriculture*, **93**, 3237-3244.
- Bader M, Hiltbrunner E, Korner C (2009) Fine root responses of mature deciduous forest trees to free air carbon dioxide enrichment (FACE). *Functional Ecology*, **23**, 913-921.
- Baggs EM, Blum H (2004) CH₄ oxidation and emissions of CH₄ and N₂O from *Lolium perenne* swards under elevated atmospheric CO₂. *Soil Biology & Biochemistry*, **36**, 713-723.
- Baggs EM, Richter M, Hartwig UA, Cadisch G (2003) Nitrous oxide emissions from grass swards during the eighth year of elevated atmospheric pCO₂ (Swiss FACE). *Global Change Biology*, **9**, 1214-1222.
- Barnard R, Barthes L, Le Roux X *et al.* (2004a) Atmospheric CO₂ elevation has little effect on nitrifying and denitrifying enzyme activity in four European grasslands. *Global Change Biology*, **10**, 488-497.
- Barnard R, Barthes L, Le Roux X, Leadley PW (2004b) Dynamics of nitrifying activities, denitrifying activities and nitrogen in grassland mesocosms as altered by elevated CO₂. *New Phytologist*, **162**, 365-376.
- Baslam M, Erice G, Goicoechea N (2012) Impact of arbuscular mycorrhizal fungi (AMF) and atmospheric CO₂ concentration on the biomass production and partitioning in the forage legume alfalfa. *Symbiosis*, **58**, 171-181.

- Berntson GM, Bazzaz FA (1997) Nitrogen cycling in microcosms of yellow birch exposed to elevated CO₂: Simultaneous positive and negative below-ground feedbacks. *Global Change Biology*, **3**, 247-258.
- Berntson GM, Bazzaz FA (1998) Regenerating temperate forest mesocosms in elevated CO₂: belowground growth and nitrogen cycling. *Oecologia*, **113**, 115-125.
- Billes G, Rouhier H, Bottner P (1993) Modifications of the Carbon and Nitrogen Allocations in the Plant (*Triticum-Aestivum* L) Soil System in Response to Increased Atmospheric CO₂ Concentration. *Plant and Soil*, **157**, 215-225.
- Billings SA, Schaeffer SM, Evans RD (2002) Trace N gas losses and N mineralization in Mojave desert soils exposed to elevated CO₂. *Soil Biology & Biochemistry*, **34**, 1777-1784.
- Billings SA, Schaeffer SM, Evans RD (2003) Nitrogen fixation by biological soil crusts and heterotrophic bacteria in an intact Mojave Desert ecosystem with elevated CO₂ and added soil carbon. *Soil Biology & Biochemistry*, **35**, 643-649.
- Billings SA, Schaeffer SM, Evans RD (2004) Soil microbial activity and N availability with elevated CO₂ in Mojave desert soils. *Global Biogeochemical Cycles*, **18**.
- Blank RR, Derner JD (2004) Effects of CO₂ enrichment on plant-soil relationships of *Lepidium latifolium*. *Plant and Soil*, **262**, 159-167.
- Bloor JMG, Niboyet A, Leadley PW, Barthes L (2009) CO₂ and inorganic N supply modify competition for N between co-occurring grass plants, tree seedlings and soil microorganisms. *Soil Biology & Biochemistry*, **41**, 544-552.
- Bradford MA, Wood SA, Maestre FT, Reynolds JF, Warren RJ (2012) Contingency in ecosystem but not plant community response to multiple global change factors. *New Phytologist*, **196**, 462-471.
- Brown ALP, Day FP, Hungate BA, Drake BG, Hinkle CR (2007) Root biomass and nutrient dynamics in a scrub-oak ecosystem under the influence of elevated atmospheric CO₂. *Plant and Soil*, **292**, 219-232.
- Cabrerizo PM, Gonzalez EM, Aparicio-Tejo PM, Arrese-Igor C (2001) Continuous CO₂ enrichment leads to increased nodule biomass, carbon availability to nodules and activity of carbon-metabolising enzymes but does not enhance specific nitrogen fixation in pea. *Physiologia Plantarum*, **113**, 33-40.
- Calfapietra C, De Angelis P, Gielen B *et al.* (2007) Increased nitrogen-use efficiency of a short-rotation poplar plantation in elevated CO₂ concentration. *Tree Physiology*, **27**, 1153-1163.
- Cantarel AaM, Bloor JMG, Deltroy N, Soussana JF (2011) Effects of Climate Change Drivers on Nitrous Oxide Fluxes in an Upland Temperate Grassland. *Ecosystems*, **14**, 223-233.
- Carnol M, Hogenboom L, Jach ME, Remacle J, Ceulemans R (2002) Elevated atmospheric CO₂ in open top chambers increases net nitrification and potential denitrification. *Global Change Biology*, **8**, 590-598.
- Carrillo Y, Dijkstra FA, Pendall E, Morgan JA, Blumenthal DM (2012) Controls over Soil Nitrogen Pools in a Semiarid Grassland Under Elevated CO₂ and Warming. *Ecosystems*, **15**, 761-774.
- Cheng L, Booker FL, Burkey KO *et al.* (2011) Soil Microbial Responses to Elevated CO₂ and O₃ in a Nitrogen-Aggrading Agroecosystem. *Plos One*, **6**.
- Cheng WG, Inubushi K, Yagi K, Sakai H, Kobayashi K (2001) Effects of elevated carbon dioxide concentration on biological nitrogen fixation, nitrogen mineralization and carbon decomposition in submerged rice soil. *Biology and Fertility of Soils*, **34**, 7-13.

- Cheng WG, Yagi K, Sakai H, Kobayashi K (2006) Effects of elevated atmospheric CO₂ concentrations on CH₄ and N₂O emission from rice soil: An experiment in controlled-environment chambers. *Biogeochemistry*, **77**, 351-373.
- Curtis PS, Balduman LM, Drake BG, Whigham DF (1990) Elevated Atmospheric CO₂ Effects on Belowground Processes in C₃ and C₄ Estuarine Marsh Communities. *Ecology*, **71**, 2001-2006.
- Daepf M, Nosberger J, Luscher A (2001) Nitrogen fertilization and developmental stage alter the response of *Lolium perenne* to elevated CO₂. *New Phytologist*, **150**, 347-358.
- Daepf M, Suter D, Almeida JPF *et al.* (2000) Yield response of *Lolium perenne* swards to free air CO₂ enrichment increased over six years in a high N input system on fertile soil. *Global Change Biology*, **6**, 805-816.
- Dakora FD, Drake BG (2000) Elevated CO₂ stimulates associative N₂ fixation in a C₃ plant of the Chesapeake Bay wetland. *Plant Cell and Environment*, **23**, 943-953.
- Das S, Bhattacharyya P, Adhya TK (2011) Impact of elevated CO₂, flooding, and temperature interaction on heterotrophic nitrogen fixation in tropical rice soils. *Biology and Fertility of Soils*, **47**, 25-30.
- De Graaff MA, Van Kessel C, Six J (2009) Rhizodeposition-induced decomposition increases N availability to wild and cultivated wheat genotypes under elevated CO₂. *Soil Biology & Biochemistry*, **41**, 1094-1103.
- Decock C, Chung H, Venterea R, Gray SB, Leakey ADB, Six J (2012) Elevated CO₂ and O₃ modify N turnover rates, but not N₂O emissions in a soybean agroecosystem. *Soil Biology & Biochemistry*, **51**, 104-114.
- Dijkstra FA, Blumenthal D, Morgan JA, Lecain DR, Follett RF (2010a) Elevated CO₂ effects on semi-arid grassland plants in relation to water availability and competition. *Functional Ecology*, **24**, 1152-1161.
- Dijkstra FA, Blumenthal D, Morgan JA, Pendall E, Carrillo Y, Follett RF (2010b) Contrasting effects of elevated CO₂ and warming on nitrogen cycling in a semiarid grassland. *New Phytologist*, **187**, 426-437.
- Dijkstra FA, Hobbie SE, Reich PB, Knops JMH (2005) Divergent effects of elevated CO₂, N fertilization, and plant diversity on soil C and N dynamics in a grassland field experiment. *Plant and Soil*, **272**, 41-52.
- Dijkstra FA, Morgan JA, Lecain DR, Follett RF (2010c) Microbially mediated CH₄ consumption and N₂O emission is affected by elevated CO₂, soil water content, and composition of semi-arid grassland species. *Plant and Soil*, **329**, 269-281.
- Dijkstra FA, West JB, Hobbie SE, Reich PB, Trost J (2007) Plant diversity, CO₂, and N influence inorganic and organic N leaching in grasslands. *Ecology*, **88**, 490-500.
- Dorodnikov M, Kuzyakov Y, Fangmeier A, Wiesenberger GLB (2011) C and N in soil organic matter density fractions under elevated atmospheric CO₂: Turnover vs. stabilization. *Soil Biology & Biochemistry*, **43**, 579-589.
- Drake JE, Oishi AC, Giasson MA, Oren R, Johnsen KH, Finzi AC (2012) Trenching reduces soil heterotrophic activity in a loblolly pine (*Pinus taeda*) forest exposed to elevated atmospheric [CO₂] and N fertilization. *Agricultural and Forest Meteorology*, **165**, 43-52.
- Duan BL, Zhang XL, Li YP, Li L, Korpelainen H, Li CY (2013) Plastic responses of *Populus yunnanensis* and *Abies faxoniana* to elevated atmospheric CO₂ and warming. *Forest Ecology and Management*, **296**, 33-40.

- Feng Z, Dyckmans J, Flessa H (2004) Effects of elevated carbon dioxide concentration on growth and N₂ fixation of young *Robinia pseudoacacia*. *Tree Physiology*, **24**, 323-330.
- Finzi AC, Delucia EH, Hamilton JG, Richter DD, Schlesinger WH (2002) The nitrogen budget of a pine forest under free air CO₂ enrichment. *Oecologia*, **132**, 567-578.
- Finzi AC, Schlesinger WH (2003) Soil-nitrogen cycling in a pine forest exposed to 5 years of elevated carbon dioxide. *Ecosystems*, **6**, 444-456.
- Franzaring J, Gensheimer G, Weller S, Schmid I, Fangmeier A (2012) Allocation and remobilisation of nitrogen in spring oilseed rape (*Brassica napus* L. cv. Mozart) as affected by N supply and elevated CO₂. *Environmental and Experimental Botany*, **83**, 12-22.
- Garten CT, Iversen CM, Norby RJ (2011) Litterfall ¹⁵N abundance indicates declining soil nitrogen availability in a free-air CO₂ enrichment experiment. *Ecology*, **92**, 133-139.
- Gill RA, Anderson LJ, Polley HW, Johnson HB, Jackson RB (2006) Potential nitrogen constraints on soil carbon sequestration under low and elevated atmospheric CO₂. *Ecology*, **87**, 41-52.
- Gill RA, Polley HW, Johnson HB, Anderson LJ, Maherali H, Jackson RB (2002) Nonlinear grassland responses to past and future atmospheric CO₂. *Nature*, **417**, 279-282.
- Gloser V, Jezikova M, Luscher A, Frehner M, Blum H, Nosberger J, Hartwig UA (2000) Soil mineral nitrogen availability was unaffected by elevated atmospheric pCO₂ in a four year old field experiment (Swiss FACE). *Plant and Soil*, **227**, 291-299.
- Gray SB, Strellner RS, Puthuval KK *et al.* (2013) Minirhizotron imaging reveals that nodulation of field-grown soybean is enhanced by free-air CO₂ enrichment only when combined with drought stress. *Functional Plant Biology*, **40**, 137-147.
- Guenet B, Lenhart K, Leloup J *et al.* (2012) The impact of long-term CO₂ enrichment and moisture levels on soil microbial community structure and enzyme activities. *Geoderma*, **170**, 331-336.
- Gutierrez D, Morcuende R, Del Pozo A, Martinez-Carrasco R, Perez P (2013) Involvement of nitrogen and cytokinins in photosynthetic acclimation to elevated CO₂ of spring wheat. *Journal of Plant Physiology*, **170**, 1337-1343.
- Hagedorn F, Bucher JB, Tarjan D, Rusert P, Bucher-Wallin I (2000) Responses of N fluxes and pools to elevated atmospheric CO₂ in model forest ecosystems with acidic and calcareous soils. *Plant and Soil*, **224**, 273-286.
- Hall JM, Paterson E, Killham K (1998) The effect of elevated CO₂ concentration and soil pH on the relationship between plant growth and rhizosphere denitrification potential. *Global Change Biology*, **4**, 209-216.
- Hartwig UA, Luscher A, Nosberger J, Van Kessel C (2002) Nitrogen-15 budget in model ecosystems of white clover and perennial ryegrass exposed for four years at elevated atmospheric pCO₂. *Global Change Biology*, **8**, 194-202.
- Hibbs DE, Chan SS, Castellano M, Niu CH (1995) Response of Red Alder Seedlings to CO₂ Enrichment and Water Stress. *New Phytologist*, **129**, 569-577.
- Hillstrom M, Meehan TD, Kelly K, Lindroth RL (2010) Soil carbon and nitrogen mineralization following deposition of insect frass and greenfall from forests under elevated CO₂ and O₃. *Plant and Soil*, **336**, 75-85.
- Hofmockel KS, Schlesinger WH (2007) Carbon dioxide effects on heterotrophic dinitrogen fixation in a temperate pine forest. *Soil Science Society of America Journal*, **71**, 140-144.

- Hoosbeek MR, Lukac M, Velthorst E, Smith AR, Godbold DL (2011) Free atmospheric CO₂ enrichment increased above ground biomass but did not affect symbiotic N₂-fixation and soil carbon dynamics in a mixed deciduous stand in Wales. *Biogeosciences*, **8**, 353-364.
- Hoosbeek MR, Scarascia-Mugnozza GE (2009) Increased Litter Build Up and Soil Organic Matter Stabilization in a Poplar Plantation After 6 Years of Atmospheric CO₂ Enrichment (FACE): Final Results of POP-EuroFACE Compared to Other Forest FACE Experiments. *Ecosystems*, **12**, 220-239.
- Hoque MM, Inubushi K, Miura S, Kobayashi K, Kim HY, Okada M, Yabashi S (2001) Biological dinitrogen fixation and soil microbial biomass carbon as influenced by free-air carbon dioxide enrichment (FACE) at three levels of nitrogen fertilization in a paddy field. *Biology and Fertility of Soils*, **34**, 453-459.
- Hovenden MJ, Newton PCD, Carran RA *et al.* (2008) Warming prevents the elevated CO₂-induced reduction in available soil nitrogen in a temperate, perennial grassland. *Global Change Biology*, **14**, 1018-1024.
- Hungate BA, Canadell J, Chapin FS (1996) Plant species mediate changes in soil microbial N in response to elevated CO₂. *Ecology*, **77**, 2505-2515.
- Hungate BA, Chapin FS, Zhong H, Holland EA, Field CB (1997a) Stimulation of grassland nitrogen cycling under carbon dioxide enrichment. *Oecologia*, **109**, 149-153.
- Hungate BA, Johnson DW, Dijkstra P *et al.* (2006) Nitrogen cycling during seven years of atmospheric CO₂ enrichment in a scrub oak woodland. *Ecology*, **87**, 26-40.
- Hungate BA, Lund CP, Pearson HL, Chapin FS (1997b) Elevated CO₂ and nutrient addition alter soil N cycling and N trace gas fluxes with early season wet-up in a California annual grassland. *Biogeochemistry*, **37**, 89-109.
- Hungate BA, Stiling PD, Dijkstra P *et al.* (2004) CO₂ elicits long-term decline in nitrogen fixation. *Science*, **304**, 1291-1291.
- Ineson P, Coward PA, Hartwig UA (1998) Soil gas fluxes of N₂O, CH₄ and CO₂ beneath *Lolium perenne* under elevated CO₂: The Swiss free air carbon dioxide enrichment experiment. *Plant and Soil*, **198**, 89-95.
- Iversen CM, Keller JK, Garten CT, Norby RJ (2012) Soil carbon and nitrogen cycling and storage throughout the soil profile in a sweetgum plantation after 11 years of CO₂-enrichment. *Global Change Biology*, **18**, 1684-1697.
- Jastrow JD, Miller RM, Matamala R, Norby RJ, Boutton TW, Rice CW, Owensby CE (2005) Elevated atmospheric carbon dioxide increases soil carbon. *Global Change Biology*, **11**, 2057-2064.
- Jastrow JD, Miller RM, Owensby CE (2000) Long-term effects of elevated atmospheric CO₂ on below-ground biomass and transformations to soil organic matter in grassland. *Plant and Soil*, **224**, 85-97.
- Jin J, Tang CX, Armstrong R, Sale P (2012) Phosphorus supply enhances the response of legumes to elevated CO₂ (FACE) in a phosphorus-deficient vertisol. *Plant and Soil*, **358**, 91-104.
- Johnson DW, Ball JT, Walker RF (1997) Effects of CO₂ and nitrogen fertilization on vegetation and soil nutrient content in juvenile ponderosa pine. *Plant and Soil*, **190**, 29-40.
- Johnson DW, Cheng W, Joslin JD, Norby RJ, Edwards NT, Todd DE (2004) Effects of elevated CO₂ on nutrient cycling in a sweetgum plantation. *Biogeochemistry*, **69**, 379-403.
- Johnson DW, Hoyleman AM, Ball JT, Walker RF (2006) Ponderosa pine responses to elevated CO₂ and nitrogen fertilization. *Biogeochemistry*, **77**, 157-175.

- Johnson DW, Hungate BA, Dijkstra P, Hymus G, Drake B (2001) Effects of elevated carbon dioxide on soils in a Florida scrub oak ecosystem. *Journal of Environmental Quality*, **30**, 501-507.
- Johnson DW, Hungate BA, Dijkstra P, Hymus G, Hinkle CR, Stiling P, Drake BG (2003) The effects of elevated CO₂ on nutrient distribution in a fire-adapted scrub oak forest. *Ecological Applications*, **13**, 1388-1399.
- Kammann C, Muller C, Grunhage L, Jager HJ (2008) Elevated CO₂ stimulates N₂O emissions in permanent grassland. *Soil Biology & Biochemistry*, **40**, 2194-2205.
- Kampichler C, Kandeler E, Bardgett RD, Jones TH, Thompson LJ (1998) Impact of elevated atmospheric CO₂ concentration on soil microbial biomass and activity in a complex, weedy field model ecosystem. *Global Change Biology*, **4**, 335-346.
- Kanerva T, Palojarvi A, Ramo K, Ojanpera K, Esala M, Manninen S (2006) A 3-year exposure to CO₂ and O₃ induced minor changes in soil N cycling in a meadow ecosystem. *Plant and Soil*, **286**, 61-73.
- Kettunen R, Saarnio S, Martikainen P, Silvola J (2005) Elevated CO₂ concentration and nitrogen fertilisation effects on N₂O and CH₄ fluxes and biomass production of *Phleum pratense* on farmed peat soil. *Soil Biology & Biochemistry*, **37**, 739-750.
- Kettunen R, Saarnio S, Martikainen PJ, Silvola J (2007) Can a mixed stand of N₂-fixing and non-fixing plants restrict N₂O emissions with increasing CO₂ concentration? *Soil Biology & Biochemistry*, **39**, 2538-2546.
- Kim HY, Lim SS, Kwak JH, Lee DS, Lee SM, Ro HM, Choi WJ (2011) Dry matter and nitrogen accumulation and partitioning in rice (*Oryza sativa* L.) exposed to experimental warming with elevated CO₂. *Plant and Soil*, **342**, 59-71.
- Lam SK, Chen D, Norton R, Armstrong R (2013a) The effect of elevated atmospheric carbon dioxide concentration on the contribution of residual legume and fertilizer nitrogen to a subsequent wheat crop. *Plant and Soil*, **364**, 81-91.
- Lam SK, Chen D, Norton R, Armstrong R, Mosier AR (2013b) Influence of elevated atmospheric carbon dioxide and supplementary irrigation on greenhouse gas emissions from a spring wheat crop in southern Australia. *Journal of Agricultural Science*, **151**, 201-208.
- Lam SK, Chen DL, Norton R, Armstrong R (2012a) Does phosphorus stimulate the effect of elevated [CO₂] on growth and symbiotic nitrogen fixation of grain and pasture legumes? *Crop & Pasture Science*, **63**, 53-62.
- Lam SK, Chen DL, Norton R, Armstrong R (2012b) Nitrogen demand and the recovery of ¹⁵N-labelled fertilizer in wheat grown under elevated carbon dioxide in southern Australia. *Nutrient Cycling in Agroecosystems*, **92**, 133-144.
- Lam SK, Chen DL, Norton R, Armstrong R (2013c) Crop residue incorporation negates the positive effect of elevated atmospheric carbon dioxide concentration on wheat productivity and fertilizer nitrogen recovery. *Plant and Soil*, **366**, 551-561.
- Lam SK, Han X, Lin ED, Norton R, Chen DL (2012c) Does elevated atmospheric carbon dioxide concentration increase wheat nitrogen demand and recovery of nitrogen applied at stem elongation? *Agriculture Ecosystems & Environment*, **155**, 142-146.
- Lam SK, Hao XY, Lin ED *et al.* (2012d) Effect of elevated carbon dioxide on growth and nitrogen fixation of two soybean cultivars in northern China. *Biology and Fertility of Soils*, **48**, 603-606.

- Lam SK, Lin ED, Norton R, Chen DL (2011) The effect of increased atmospheric carbon dioxide concentration on emissions of nitrous oxide, carbon dioxide and methane from a wheat field in a semi-arid environment in northern China. *Soil Biology & Biochemistry*, **43**, 458-461.
- Langley JA, Mckinley DC, Wolf AA, Hungate BA, Drake BG, Megonigal JP (2009) Priming depletes soil carbon and releases nitrogen in a scrub-oak ecosystem exposed to elevated CO₂. *Soil Biology & Biochemistry*, **41**, 54-60.
- Larsen KS, Andresen LC, Beier C *et al.* (2011) Reduced N cycling in response to elevated CO₂, warming, and drought in a Danish heathland: Synthesizing results of the CLIMAITE project after two years of treatments. *Global Change Biology*, **17**, 1884-1899.
- Lee TD, Reich PB, Tjoelker MG (2003) Legume presence increases photosynthesis and N concentrations of co-occurring non-fixers but does not modulate their responsiveness to carbon dioxide enrichment. *Oecologia*, **137**, 22-31.
- Lichter J, Billings SA, Ziegler SE *et al.* (2008) Soil carbon sequestration in a pine forest after 9 years of atmospheric CO₂ enrichment. *Global Change Biology*, **14**, 2910-2922.
- Liu JX, Zhang DQ, Zhou GY, Faivre-Vuillin B, Deng Q, Wang CL (2008) CO₂ enrichment increases nutrient leaching from model forest ecosystems in subtropical China. *Biogeosciences*, **5**, 1783-1795.
- Liu LL, King JS, Giardina CP (2007) Effects of elevated atmospheric CO₂ and tropospheric O₃ on nutrient dynamics: decomposition of leaf litter in trembling aspen and paper birch communities. *Plant and Soil*, **299**, 65-82.
- Long X, Chen CR, Xu ZH, Oren R, He JZ (2012) Abundance and community structure of ammonia-oxidizing bacteria and archaea in a temperate forest ecosystem under ten-years elevated CO₂. *Soil Biology & Biochemistry*, **46**, 163-171.
- Luscher A, Hartwig UA, Suter D, Nosberger J (2000) Direct evidence that symbiotic N₂ fixation in fertile grassland is an important trait for a strong response of plants to elevated atmospheric CO₂. *Global Change Biology*, **6**, 655-662.
- Martin-Olmedo P, Rees RM, Grace J (2002) The influence of plants grown under elevated CO₂ and N fertilization on soil nitrogen dynamics. *Global Change Biology*, **8**, 643-657.
- Mckinley DC, Romero JC, Hungate BA, Drake BG, Megonigal JP (2009) Does deep soil N availability sustain long-term ecosystem responses to elevated CO₂? *Global Change Biology*, **15**, 2035-2048.
- Mikan CJ, Zak DR, Kubiske ME, Pregitzer KS (2000) Combined effects of atmospheric CO₂ and N availability on the belowground carbon and nitrogen dynamics of aspen mesocosms. *Oecologia*, **124**, 432-445.
- Millett J, Godbold D, Smith AR, Grant H (2012) N₂ fixation and cycling in *Alnus glutinosa*, *Betula pendula* and *Fagus sylvatica* woodland exposed to free air CO₂ enrichment. *Oecologia*, **169**, 541-552.
- Mosier AR, Morgan JA, King JY, Lecain D, Milchunas DG (2002) Soil-atmosphere exchange of CH₄, CO₂, NO_x, and N₂O in the Colorado shortgrass steppe under elevated CO₂. *Plant and Soil*, **240**, 201-211.
- Nam HS, Kwak JH, Lim SS *et al.* (2013) Fertilizer N uptake of paddy rice in two soils with different fertility under experimental warming with elevated CO₂. *Plant and Soil*, **369**, 563-575.
- Newton PCD, Clark H, Bell CC *et al.* (1995) Plant growth and soil processes in temperate grassland communities at elevated CO₂. *Journal of Biogeography*, **22**, 235-240.

- Nguyen NT, Mohapatra PK, Fujita K (2006) Elevated CO₂ alleviates the effects of low P on the growth of N₂-fixing *Acacia auriculiformis* and *Acacia mangium*. *Plant and Soil*, **285**, 369-379.
- Niboyet A, Barthes L, Hungate BA *et al.* (2010) Responses of soil nitrogen cycling to the interactive effects of elevated CO₂ and inorganic N supply. *Plant and Soil*, **327**, 35-47.
- Niboyet A, Brown JR, Dijkstra P *et al.* (2011) Global Change Could Amplify Fire Effects on Soil Greenhouse Gas Emissions. *Plos One*, **6**.
- Niklaus PA, Alpehi D, Ebersberger D, Kampichler C, Kandeler E, Tscherko D (2003) Six years of in situ CO₂ enrichment evoke changes in soil structure and soil biota of nutrient-poor grassland. *Global Change Biology*, **9**, 585-600.
- Niklaus PA, Leadley PW, Stocklin J, Korner C (1998) Nutrient relations in calcareous grassland under elevated CO₂. *Oecologia*, **116**, 67-75.
- Nitschelm JJ, Luscher A, Hartwig UA, Vankessel C (1997) Using stable isotopes to determine soil carbon input differences under ambient and elevated atmospheric CO₂ conditions. *Global Change Biology*, **3**, 411-416.
- Norby RJ (1987) Nodulation and Nitrogenase Activity in Nitrogen-Fixing Woody-Plants Stimulated by CO₂ Enrichment of the Atmosphere. *Physiologia Plantarum*, **71**, 77-82.
- Norby RJ, Iversen CM (2006) Nitrogen uptake, distribution, turnover, and efficiency of use in a CO₂-enriched sweetgum forest. *Ecology*, **87**, 5-14.
- Oikawa S, Miyagi KM, Hikosaka K *et al.* (2010) Interactions between elevated CO₂ and N₂-fixation determine soybean yield-a test using a non-nodulated mutant. *Plant and Soil*, **330**, 163-172.
- Olszyk DM, Johnson MG, Phillips DL, Seidler RJ, Tingey DT, Watrud LS (2001) Interactive effects of CO₂ and O₃ on a ponderosa pine plant/litter/soil mesocosm. *Environmental Pollution*, **115**, 447-462.
- Pang J, Zhu JG, Xie ZB *et al.* (2006) A new explanation of the N concentration decrease in tissues of rice (*Oryza sativa* L.) exposed to elevated atmospheric pCO₂. *Environmental and Experimental Botany*, **57**, 98-105.
- Perez-Lopez U, Robredo A, Miranda-Apodaca J, Lacuesta M, Munoz-Rueda A, Mena-Petite A (2013) Carbon dioxide enrichment moderates salinity-induced effects on nitrogen acquisition and assimilation and their impact on growth in barley plants. *Environmental and Experimental Botany*, **87**, 148-158.
- Phillips RL, Whalen SC, Schlesinger WH (2001) Influence of atmospheric CO₂ enrichment on nitrous oxide flux in a temperate forest ecosystem. *Global Biogeochemical Cycles*, **15**, 741-752.
- Phillips RP, Meier IC, Bernhardt ES, Grandy AS, Wickings K, Finzi AC (2012) Roots and fungi accelerate carbon and nitrogen cycling in forests exposed to elevated CO₂. *Ecology Letters*, **15**, 1042-1049.
- Pinay G, Barbera P, Carreras-Palou A *et al.* (2007) Impact of atmospheric CO₂ and plant life forms on soil microbial activities. *Soil Biology & Biochemistry*, **39**, 33-42.
- Pleijel H, Sild J, Danielsson H, Klemetsson L (1998) Nitrous oxide emissions from a wheat field in response to elevated carbon dioxide concentration and open-top chamber enclosure. *Environmental Pollution*, **102**, 167-171.
- Polley HW, Johnson HB, Mayeux HS (1997) Leaf physiology, production, water use, and nitrogen dynamics of the grassland invader *Acacia smallii* at elevated CO₂ concentrations. *Tree Physiology*, **17**, 89-96.

- Pregitzer KS, Zak DR, Curtis PS, Kubiske ME, Teeri JA, Vogel CS (1995) Atmospheric CO₂, Soil-Nitrogen and Turnover of Fine Roots. *New Phytologist*, **129**, 579-585.
- Prior SA, Torbert HA, Runion GB *et al.* (1997) Free-air carbon dioxide enrichment of wheat: Soil carbon and nitrogen dynamics. *Journal of Environmental Quality*, **26**, 1161-1166.
- Rakshit R, Patra AK, Pal D, Kumar M, Singh R (2012) Effect of Elevated CO₂ and Temperature on Nitrogen Dynamics and Microbial Activity During Wheat (*Triticum aestivum* L.) Growth on a Subtropical Inceptisol in India. *Journal of Agronomy and Crop Science*, **198**, 452-465.
- Reich PB, Hobbie SE (2013) Decade-long soil nitrogen constraint on the CO₂ fertilization of plant biomass. *Nature Climate Change*, **3**, 278-282.
- Reich PB, Tilman D, Craine J *et al.* (2001) Do species and functional groups differ in acquisition and use of C, N and water under varying atmospheric CO₂ and N availability regimes? A field test with 16 grassland species. *New Phytologist*, **150**, 435-448.
- Ross DJ, Newton PCD, Tate KR, Luo DW (2013) Impact of a low level of CO₂ enrichment on soil carbon and nitrogen pools and mineralization rates over ten years in a seasonally dry, grazed pasture. *Soil Biology & Biochemistry*, **58**, 265-274.
- Ross DJ, Tate KR, Newton PCD (1995) Elevated CO₂ and Temperature Effects on Soil Carbon and Nitrogen Cycling in Ryegrass/White Clover Turves of an Endoaquept Soil. *Plant and Soil*, **176**, 37-49.
- Roy KS, Bhattacharyya P, Neogi S, Rao KS, Adhya TK (2012) Combined effect of elevated CO₂ and temperature on dry matter production, net assimilation rate, C and N allocations in tropical rice (*Oryza sativa* L.). *Field Crops Research*, **139**, 71-79.
- Runion GB, Entry JA, Prior SA, Mitchell RJ, Rogers HH (1999) Tissue chemistry and carbon allocation in seedlings of *Pinus palustris* subjected to elevated atmospheric CO₂ and water stress. *Tree Physiology*, **19**, 329-335.
- Rutting T, Clough TJ, Muller C, Lieffering M, Newton PCD (2010) Ten years of elevated atmospheric carbon dioxide alters soil nitrogen transformations in a sheep-grazed pasture. *Global Change Biology*, **16**, 2530-2542.
- Schleppi P, Bucher-Wallin I, Hagedorn F, Korner C (2012) Increased nitrate availability in the soil of a mixed mature temperate forest subjected to elevated CO₂ concentration (canopy FACE). *Global Change Biology*, **18**, 757-768.
- Schlesinger WH, Lichter J (2001) Limited carbon storage in soil and litter of experimental forest plots under increased atmospheric CO₂. *Nature*, **411**, 466-469.
- Schortemeyer M, Atkin OK, Mcfarlane N, Evans JR (2002) N₂ fixation by *Acacia* species increases under elevated atmospheric CO₂. *Plant Cell and Environment*, **25**, 567-579.
- Serraj R, Sinclair TR (2003) Evidence that carbon dioxide enrichment alleviates ureide-induced decline of nodule nitrogenase activity. *Annals of Botany*, **91**, 85-89.
- Sherwin GL, George L, Kannangara K, Tissue DT, Ghannoum O (2013) Impact of industrial-age climate change on the relationship between water uptake and tissue nitrogen in eucalypt seedlings. *Functional Plant Biology*, **40**, 201-212.
- Shimono H, Konno T, Sakai H, Sameshima R (2012) Interactive Effects of Elevated Atmospheric CO₂ and Waterlogging on Vegetative Growth of Soybean (*Glycine max* (L.) Merr.). *Plant Production Science*, **15**, 238-245.
- Smart DR, Ritchie K, Stark JM, Bugbee B (1997) Evidence that elevated CO₂ levels can indirectly increase rhizosphere denitrifier activity. *Applied and Environmental Microbiology*, **63**, 4621-4624.

- Smith KE, Runion GB, Prior SA, Rogers HH, Torbert HA (2010) Effects of Elevated CO₂ and Agricultural Management on Flux of Greenhouse Gases From Soil. *Soil Science*, **175**, 349-356.
- Soussana JF, Casella E, Loiseau P (1996) Long-term effects of CO₂ enrichment and temperature increase on a temperate grass sward .II. Plant nitrogen budgets and root fraction. *Plant and Soil*, **182**, 101-114.
- Talhelm AF, Pregitzer KS, Giardina CP (2012) Long-Term Leaf Production Response to Elevated Atmospheric Carbon Dioxide and Tropospheric Ozone. *Ecosystems*, **15**, 71-82.
- Temperton VM, Grayston SJ, Jackson G, Barton CVM, Millard P, Jarvis PG (2003) Effects of elevated carbon dioxide concentration on growth and nitrogen fixation in *Alnus glutinosa* in a long-term field experiment. *Tree Physiology*, **23**, 1051-1059.
- Thomas RB, Bashkin MA, Richter DD (2000) Nitrogen inhibition of nodulation and N₂ fixation of a tropical N₂-fixing tree (*Gliricidia sepium*) grown in elevated atmospheric CO₂. *New Phytologist*, **145**, 233-243.
- Tingey DT, Mckane RB, Olszyk DM, Johnson MG, Rygiewicz PT, Lee EH (2003) Elevated CO₂ and temperature alter nitrogen allocation in Douglas-fir. *Global Change Biology*, **9**, 1038-1050.
- Tobita H, Uemura A, Kitao M, Kitaoka S, Utsugi H (2010) Interactive effects of elevated CO₂, phosphorus deficiency, and soil drought on nodulation and nitrogenase activity in *Alnus hirsuta* and *Alnus maximowiczii*. *Symbiosis*, **50**, 59-69.
- Torbert HA, Prior SA, Rogers HH, Runion GB (2004) Elevated atmospheric CO₂ effects on N fertilization in grain sorghum and soybean. *Field Crops Research*, **88**, 57-67.
- Tscherko D, Kandeler E, Jones TH (2001) Effect of temperature on below-ground N-dynamics in a weedy model ecosystem at ambient and elevated atmospheric CO₂ levels. *Soil Biology & Biochemistry*, **33**, 491-501.
- Tu C, Booker FL, Burkey KO, Hu SJ (2009) Elevated Atmospheric Carbon Dioxide and O₃ Differentially Alter Nitrogen Acquisition in Peanut. *Crop Science*, **49**, 1827-1836.
- Van Groenigen KJ, Harris D, Horwath WR, Hartwig UA, Van Kessel C (2002) Linking sequestration of ¹³C and ¹⁵N in aggregates in a pasture soil following 8 years of elevated atmospheric CO₂. *Global Change Biology*, **8**, 1094-1108.
- Van Kessel C, Boots B, De Graaff MA, Harris D, Blum H, Six J (2006) Total soil C and N sequestration in a grassland following 10 years of free air CO₂ enrichment. *Global Change Biology*, **12**, 2187-2199.
- Verburg PSJ, Cheng W, Johnson DW, Schorran DE (2004) Nonsymbiotic nitrogen fixation in 3-year-old Jeffrey pines and the role of elevated [CO₂]. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere*, **34**, 1979-1984.
- Vogel CS, Curtis PS, Thomas RB (1997) Growth and nitrogen accretion of dinitrogen-fixing *Alnus glutinosa* (L) Gaertn under elevated carbon dioxide. *Plant Ecology*, **130**, 63-70.
- Weerakoon WMW, Ingram KT, Moss DN (2005) Atmospheric CO₂ concentration effects on N partitioning and fertilizer N recovery in field grown rice (*Oryza sativa* L.). *Agriculture Ecosystems & Environment*, **108**, 342-349.
- Weigel HJ, Manderscheid R (2012) Crop growth responses to free air CO₂ enrichment and nitrogen fertilization: Rotating barley, ryegrass, sugar beet and wheat. *European Journal of Agronomy*, **43**, 97-107.

- Welzmler JT, Matthias AD, White S, Thompson TL (2008) Elevated carbon dioxide and irrigation effects on soil nitrogen gas exchange in irrigated sorghum. *Soil Science Society of America Journal*, **72**, 393-401.
- West JB, Hillerislambers J, Lee TD, Hobbie SE, Reich PB (2005) Legume species identity and soil nitrogen supply determine symbiotic nitrogen-fixation responses to elevated atmospheric [CO₂]. *New Phytologist*, **167**, 523-530.
- Williams MA, Rice CW, Owensby CE (2000) Carbon dynamics and microbial activity in tallgrass prairie exposed to elevated CO₂ for 8 years. *Plant and Soil*, **227**, 127-137.
- Wood CW, Torbert HA, Rogers HH, Runion GB, Prior SA (1994) Free-Air CO₂ Enrichment Effects on Soil Carbon and Nitrogen. *Agricultural and Forest Meteorology*, **70**, 103-116.
- Zak DR, Holmes WE, Pregitzer KS (2007) Atmospheric CO₂ and O₃ alter the flow of ¹⁵N in developing forest ecosystems. *Ecology*, **88**, 2630-2639.
- Zak DR, Pregitzer KS, Curtis PS, Holmes WE (2000a) Atmospheric CO₂ and the composition and function of soil microbial communities. *Ecological Applications*, **10**, 47-59.
- Zak DR, Pregitzer KS, Curtis PS, Teeri JA, Fogel R, Randlett DL (1993) Elevated Atmospheric CO₂ and Feedback between Carbon and Nitrogen Cycles. *Plant and Soil*, **151**, 105-117.
- Zak DR, Pregitzer KS, Curtis PS, Vogel CS, Holmes WE, Lussenhop J (2000b) Atmospheric CO₂, soil-N availability, and allocation of biomass and nitrogen by *Populus tremuloides*. *Ecological Applications*, **10**, 34-46.
- Zak DR, Pregitzer KS, Kubiske ME, Burton AJ (2011) Forest productivity under elevated CO₂ and O₃: positive feedbacks to soil N cycling sustain decade-long net primary productivity enhancement by CO₂. *Ecology Letters*, **14**, 1220-1226.
- Zanetti S, Hartwig UA, Luscher A *et al.* (1996) Stimulation of symbiotic N₂ fixation in *Trifolium repens* L. under elevated atmospheric pCO₂ in a grassland ecosystem. *Plant Physiology*, **112**, 575-583.
- Zeng Q, Liu BA, Gilna B *et al.* (2011) Elevated CO₂ effects on nutrient competition between a C₃ crop (*Oryza sativa* L.) and a C₄ weed (*Echinochloa crusgalli* L.). *Nutrient Cycling in Agroecosystems*, **89**, 93-104.