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23-27 July 2012, Vienna, Austria

Effect of elevated carbon dioxide on nitrogen dynamics in grain crop and legume pasture systems

– FACE experiments and a meta-analysis

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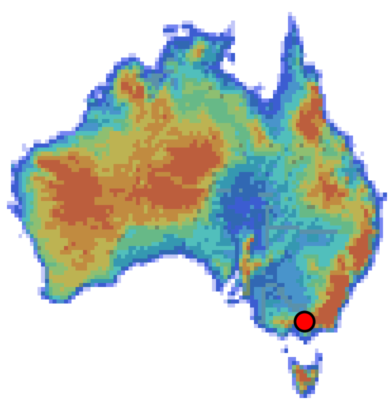

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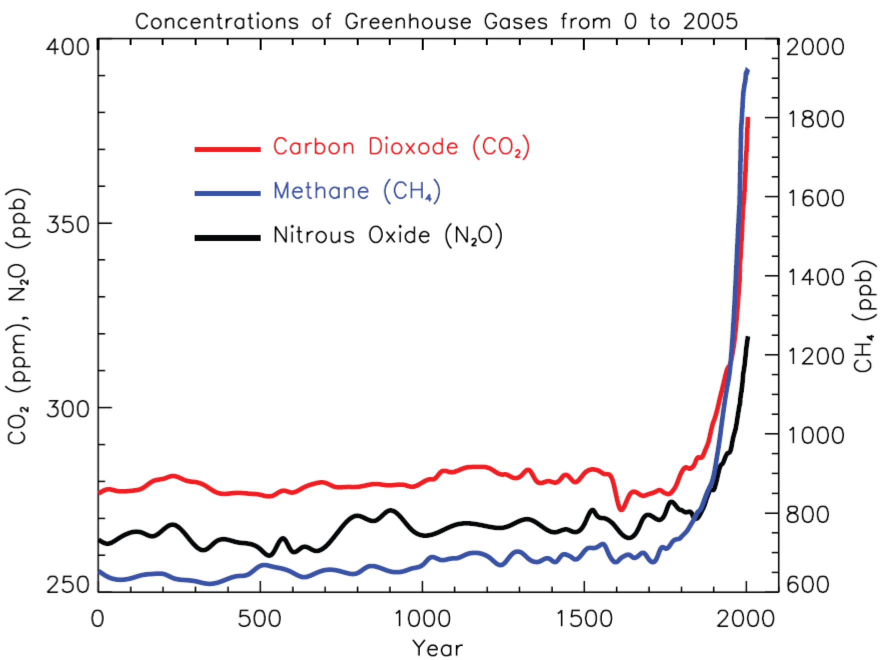
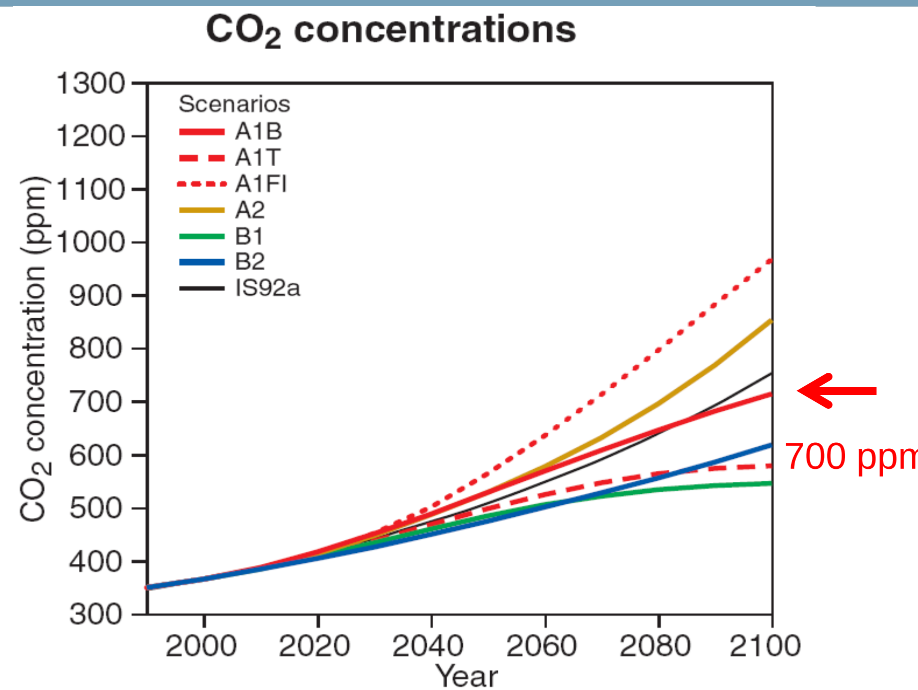
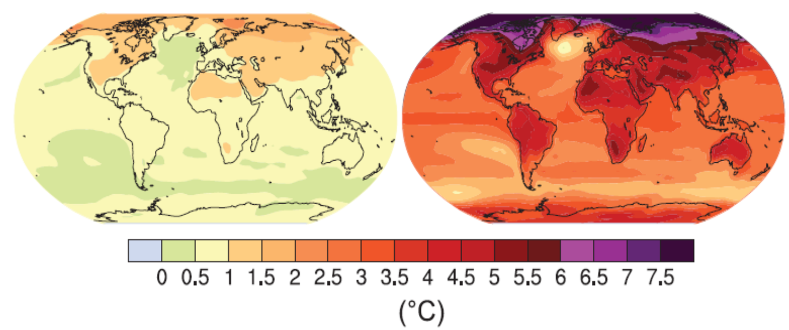
Global climate change



Concentration of greenhouse gases from 0 to 2005 (Forster et al. 2007)





Projected temperature changes relative to the period 1980–1999 (IPCC 2007)

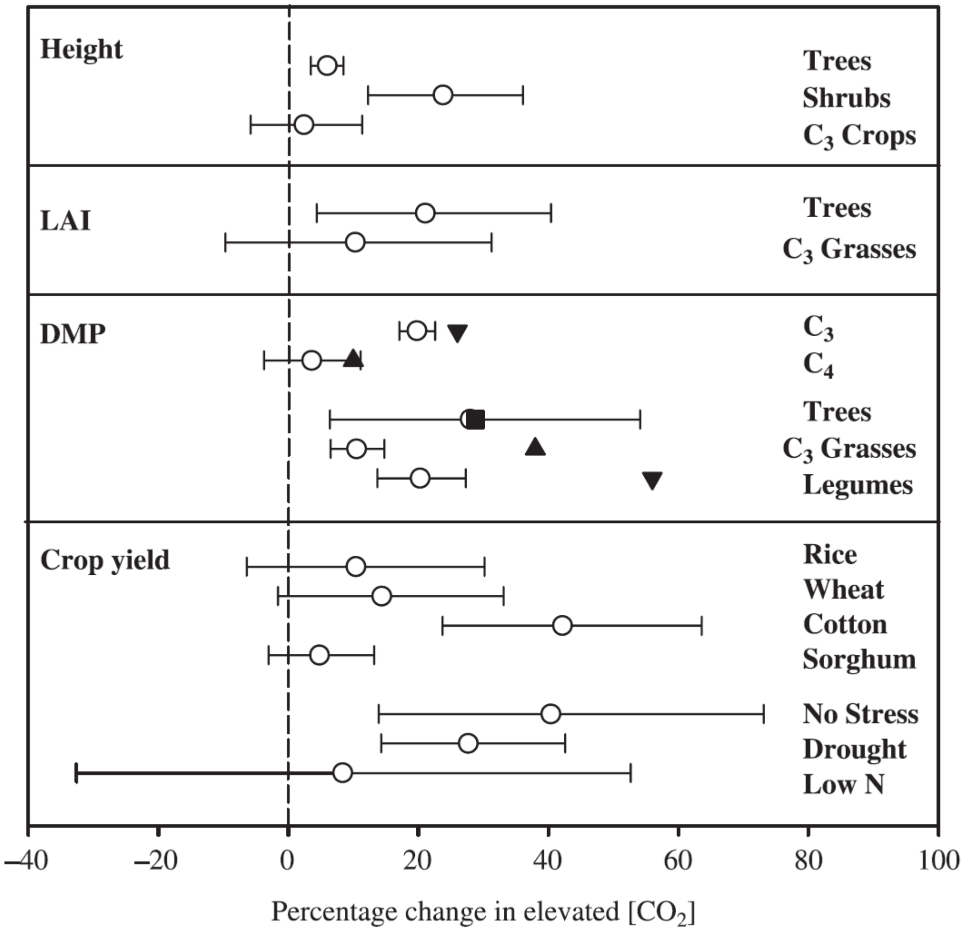
eCO_2 effects on photosynthetic and growth parameters

↑ CO_2 → ↑ photosynthetic C assimilation

↓

↑ NPP

- Elevated [CO_2] increased photosynthetic carbon assimilation by 23–46%
- Increased dry mass production of various functional group (20–28%), but not for C_4 species
- Change in water use and C input (to soil)
- Consequent impact in soil N dynamics



(Ainsworth & Long 2005)

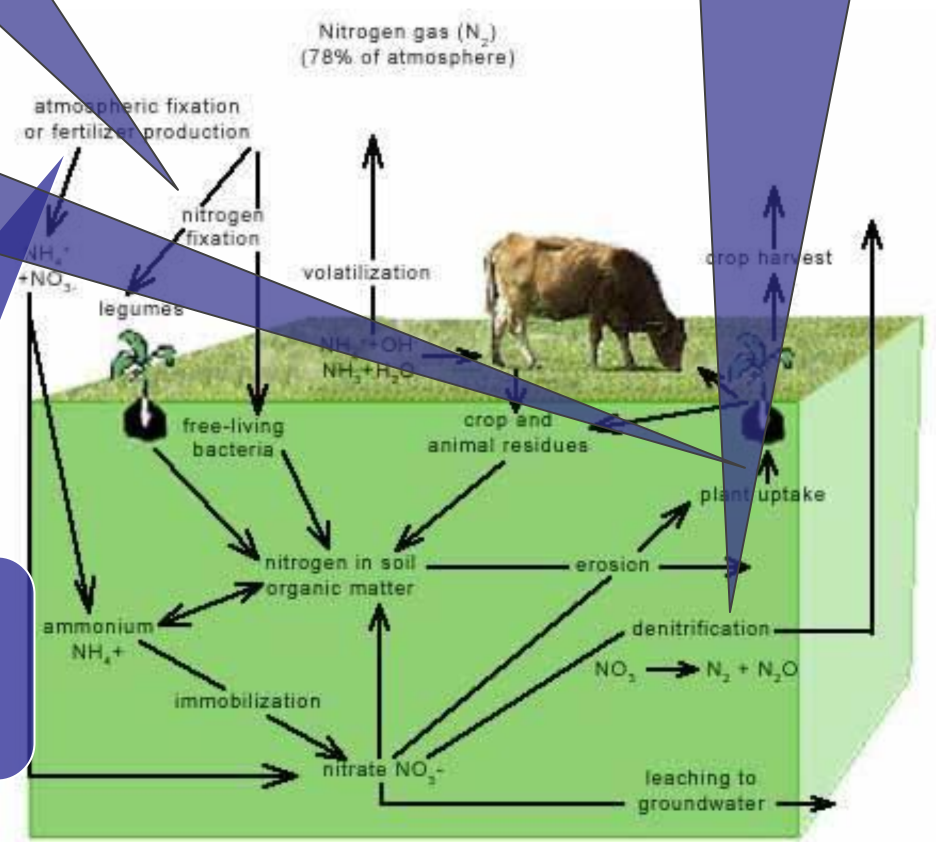
Possible eCO_2 effects on soil N dynamics

eCO_2 → more C supply to nodules → fix more N_2?

eCO_2 → more C substrates for denitrifiers → higher N_2O emissions?

eCO_2 → higher root and biomass → better access to N sources → higher N uptake and grain N removal?

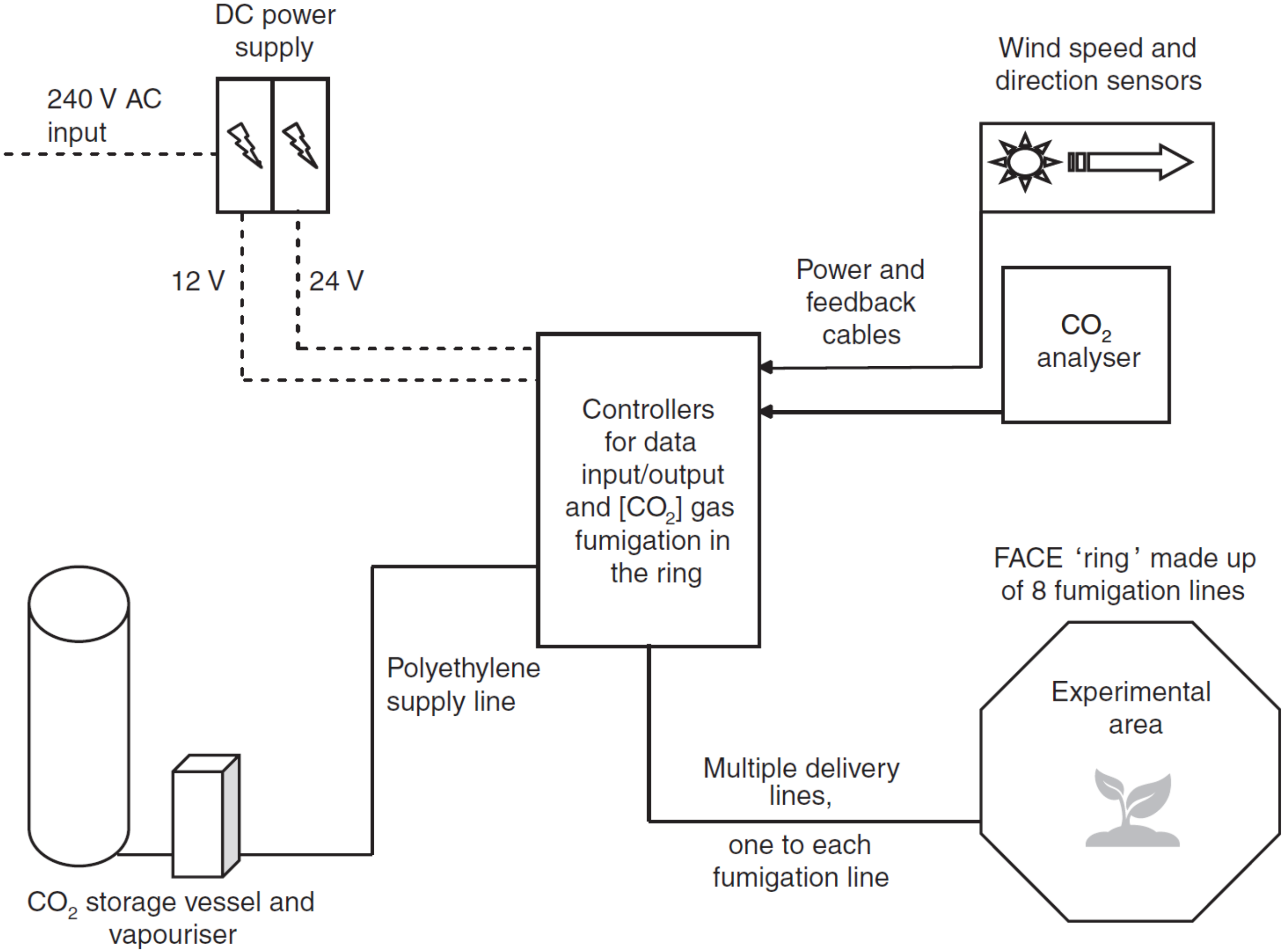
eCO_2 → higher N demand → higher fertilizer-N uptake/efficiency?



Adopted from National Sustainable Agriculture Information Service

FACE facility to study the eCO_2 agro-ecosystems

Free-
Air
Carbon dioxide
Enrichment



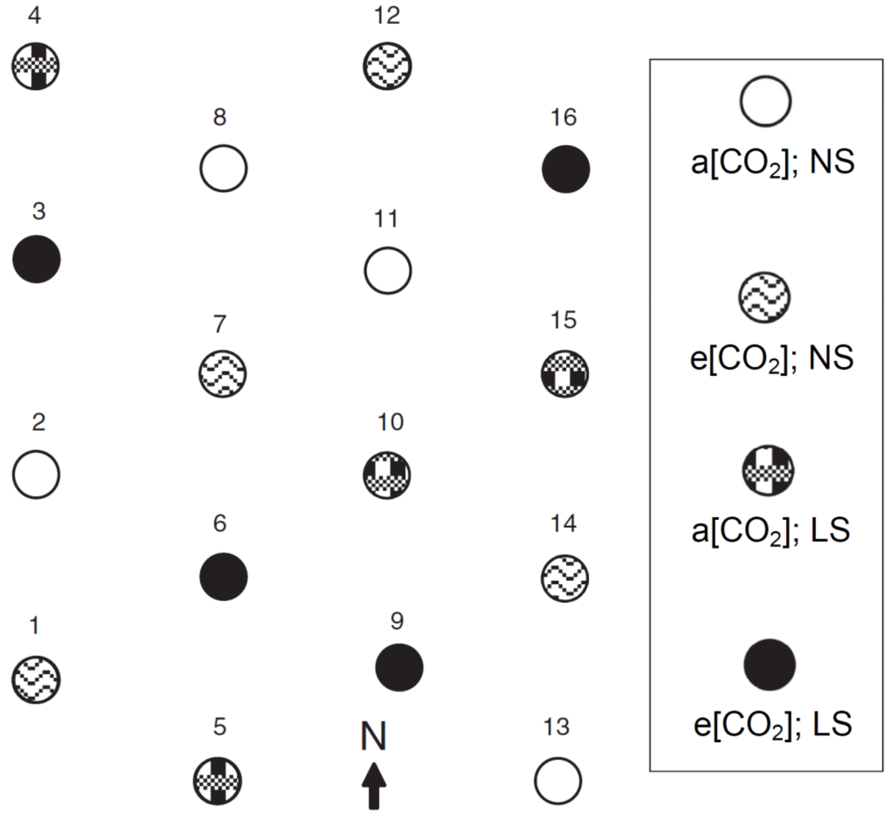
(Mollah et al. 2009)

Site location

Horsham (36˚45’S, 142˚07’E) Victoria, Australia

Source: wwp.greenwichmeantime.com

Experimental layout



<u>16 experimental areas</u>

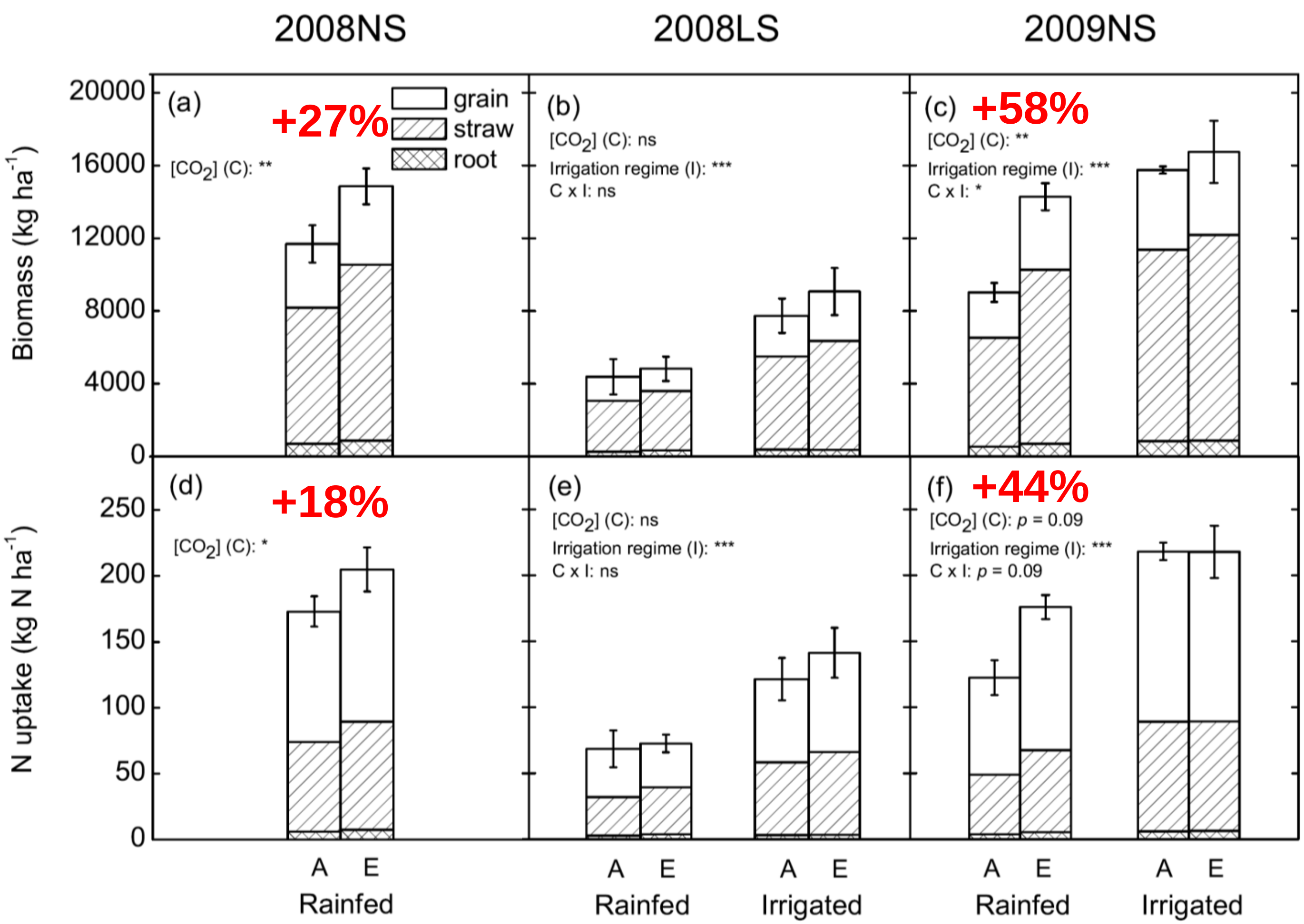
- 12 m diameter in 2008;
  16 m in 2009
- 8 elevated [CO_2] (550 μmol mol^{-1});
  8 ambient [CO_2] (390 μmol mol^{-1})
- 8 normal sowing (NS);
  8 late sowing (LS)

Fertilizer N recovery – wheat

- PVC microplot (diameter 0.24 m; height 0.25 m) inserted to 0.20 m depth
- ^{15}N-enriched (10.22 atom%) granular urea applied at 50 kg N ha^{-1}
- ^{15}N atom% analysis by IRMS

Biomass and N uptake

- Elevated [CO_2] increased total biomass and N uptake in a normal growing season.



- The removal of N in the grain under elevated [CO_2] (75 -118 kg N ha^{-1}) > ambient [CO_2] (63 -101 kg N ha^{-1}). *Lam et al, 2012, Nutr Cycl Agroecosyst 92:133–144*

Fertilizer N recovery

- Elevated [CO_2] generally had no significant effect on fertilizer N recovery in plant or in soil.

	Fertilizer N recovery (%)					
	plant	soil	plant	soil	plant	soil
	2008NS		2008LS		2009NS	
Rainfed						
Ambient [CO_2]	45.9	27.8	4.0	82.0	38.5	30.5
Elevated [CO_2]	47.2	25.8	4.1	77.9	42.3	26.5
Irrigated						
Ambient [CO_2]	--	--	24.5	60.5	47.5	22.5
Elevated [CO_2]	--	--	31.9	53.9	44.2	25.9
	Analysis of variance (ANOVA)					
[CO_2]	ns	ns	ns	ns	ns	ns
Irrigation regime	--	--	***	***	0.06	*
[CO_2] × Irrigation regime	--	--	ns	ns	ns	*

Lam et al, 2012, Nutr Cycl Agroecosyst , 92:133–144

Greenhouse gas emissions

- Static chambers (diameter 0.24 m; height 0.25 m)
- N_2O, CO_2 and CH_4 were analysed by gas chromatography

Effect of eCO_2 on GHG emissions

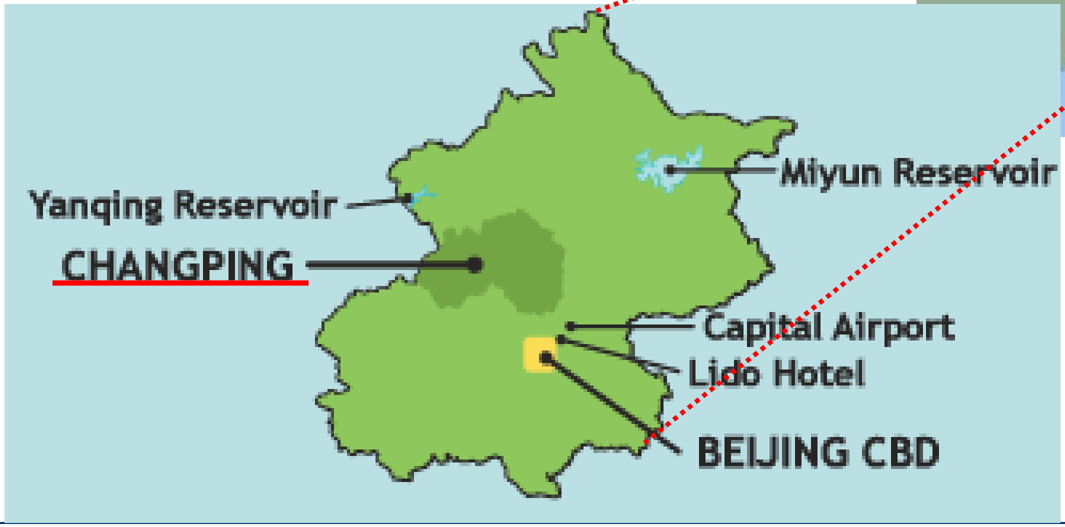
- Elevated [CO_2] increased the emissions of N_2O (92-134%) and CO_2 (16-46%), but had no significant effect on CH_4 flux.
- Supplementary irrigation appeared to reduce N_2O emissions (36%), suggesting the reduction of N_2O to N_2 in denitrification process (WFPS > 70%).

	N_2O (µg N m^{-2} h^{-1})	CO_2 (mg C m^{-2} h^{-1})	CH_4 (µg C m^{-2} h^{-1})
Ambient [CO_2]			
Rainfed	27.7 (± 8.6)	259.7 (± 25.7)	–0.56 (± 0.97)
Supplementary irrigated	15.6 (± 3.8)	327.6 (± 37.3)	0.29 (± 0.71)
Elevated [CO_2]			
Rainfed	53.3 (± 14.6)	379.7 (± 46.7)	7.06 (± 5.99)
Supplementary irrigated	36.5 (± 9.8)	378.7 (± 40.6)	–0.24 (± 1.37)

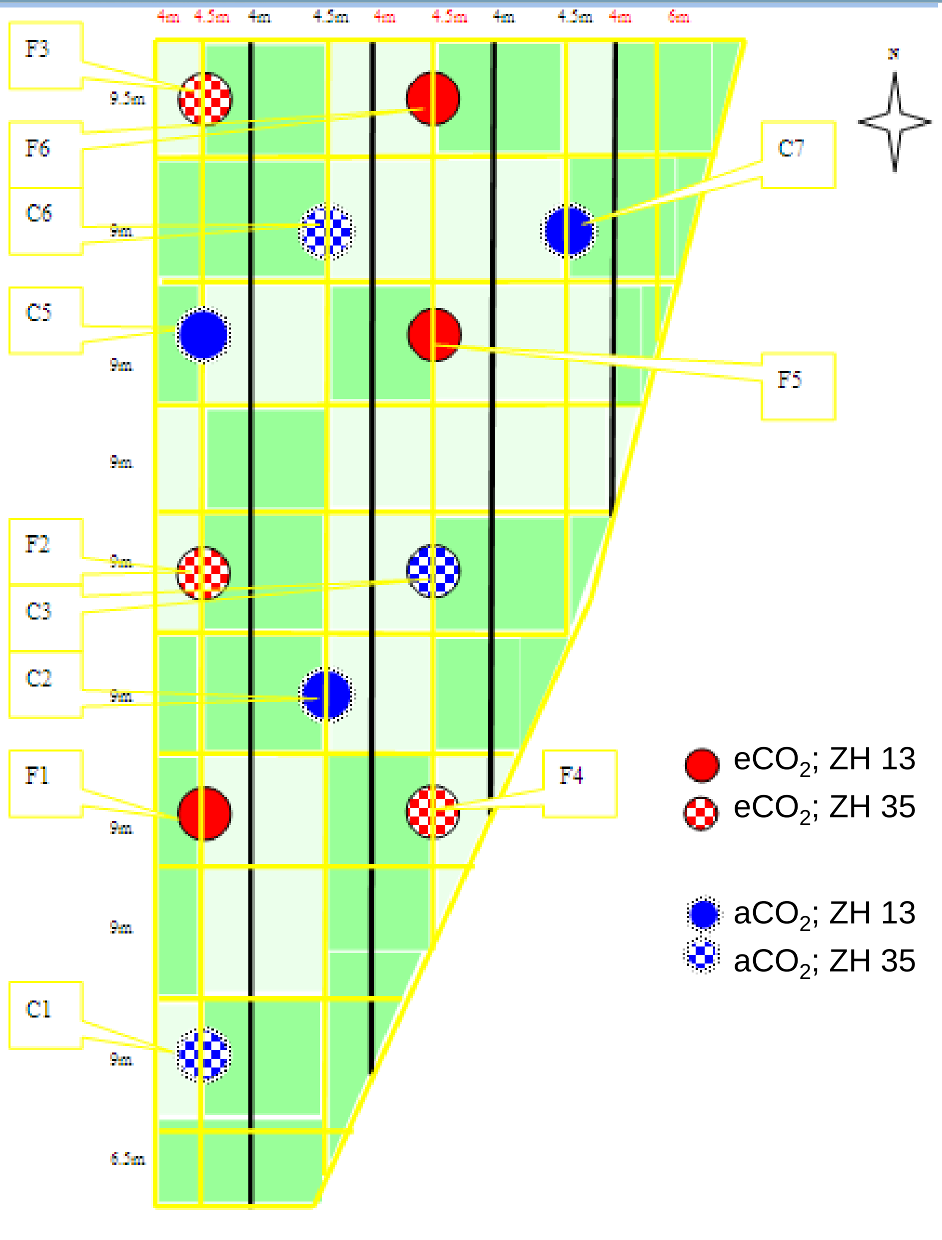
Lam et al, 2012, The Journal of Agricultural Science

Site location

Changping (40°10'N, 116°14'E)
Beijing, China



Experimental layout – soybean N_2 fixation



12 experimental areas

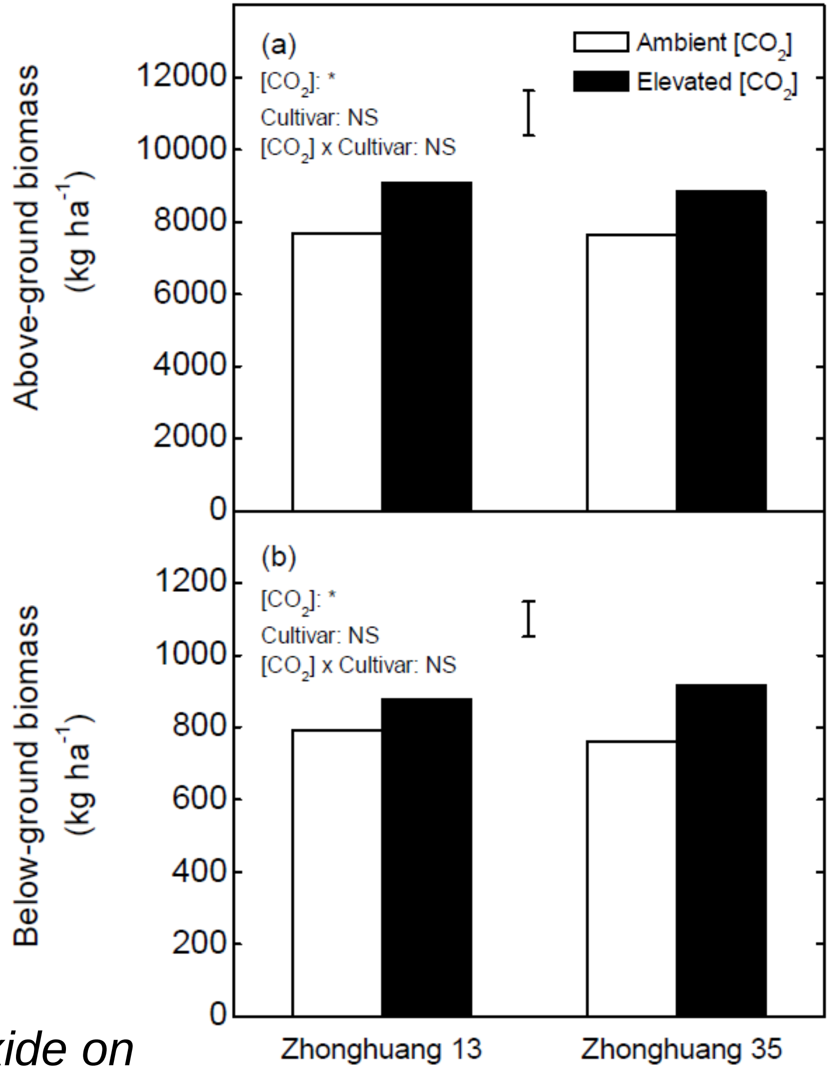
- 4 m diameter
- 6 elevated [CO_2] (550 μmol mol^{-1}); 6 ambient [CO_2] (415 μmol mol^{-1})
- 6 plots for Zhonghuang 13 (ZH 13) 6 for Zhonghuang 35 (ZH 35)

Biomass of soybean

- Elevated $[CO_2]$ increased:

  above-ground biomass (16-18%)

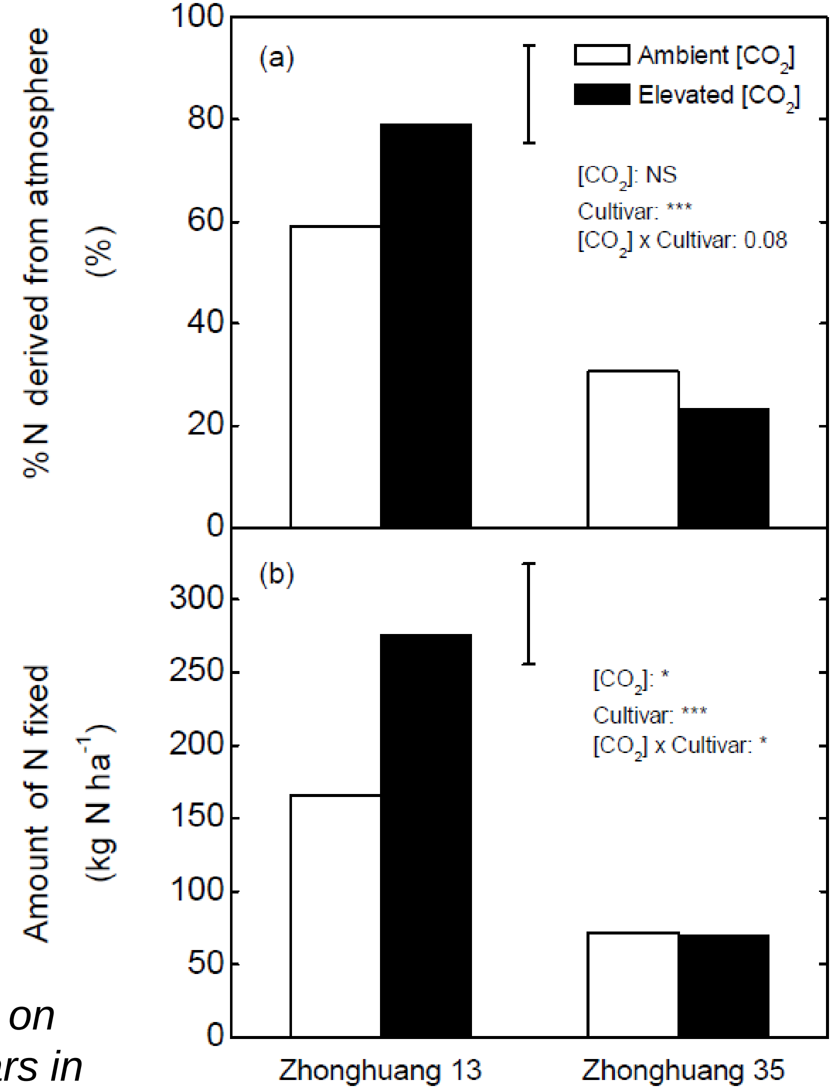
  below-ground biomass (11-20%)



Lam, et al, 2012. Effect of elevated carbon dioxide on growth and nitrogen fixation of two soybean cultivars in northern China. Biology & Fertility of Soils,48:603–606.

Effect of eCO_2 on biological N_2 fixation

- Elevated $[CO_2]$ increased %Ndfa for Zhonghuang 13 from 59 to 79%, but not Zhonghuang 35.
- Elevated $[CO_2]$ increased the amount of N fixed by Zhonghuang 13 from 165 to 275 kg N ha^{-1}, but not for Zhonghuang 35.



Lam, et al, 2012. Effect of elevated carbon dioxide on growth and nitrogen fixation of two soybean cultivars in northern China. Biology & Fertility of Soils,48:603–606.

Meta-analysis of

"N dynamics in grain crop and legume pasture systems under elevated CO_2"

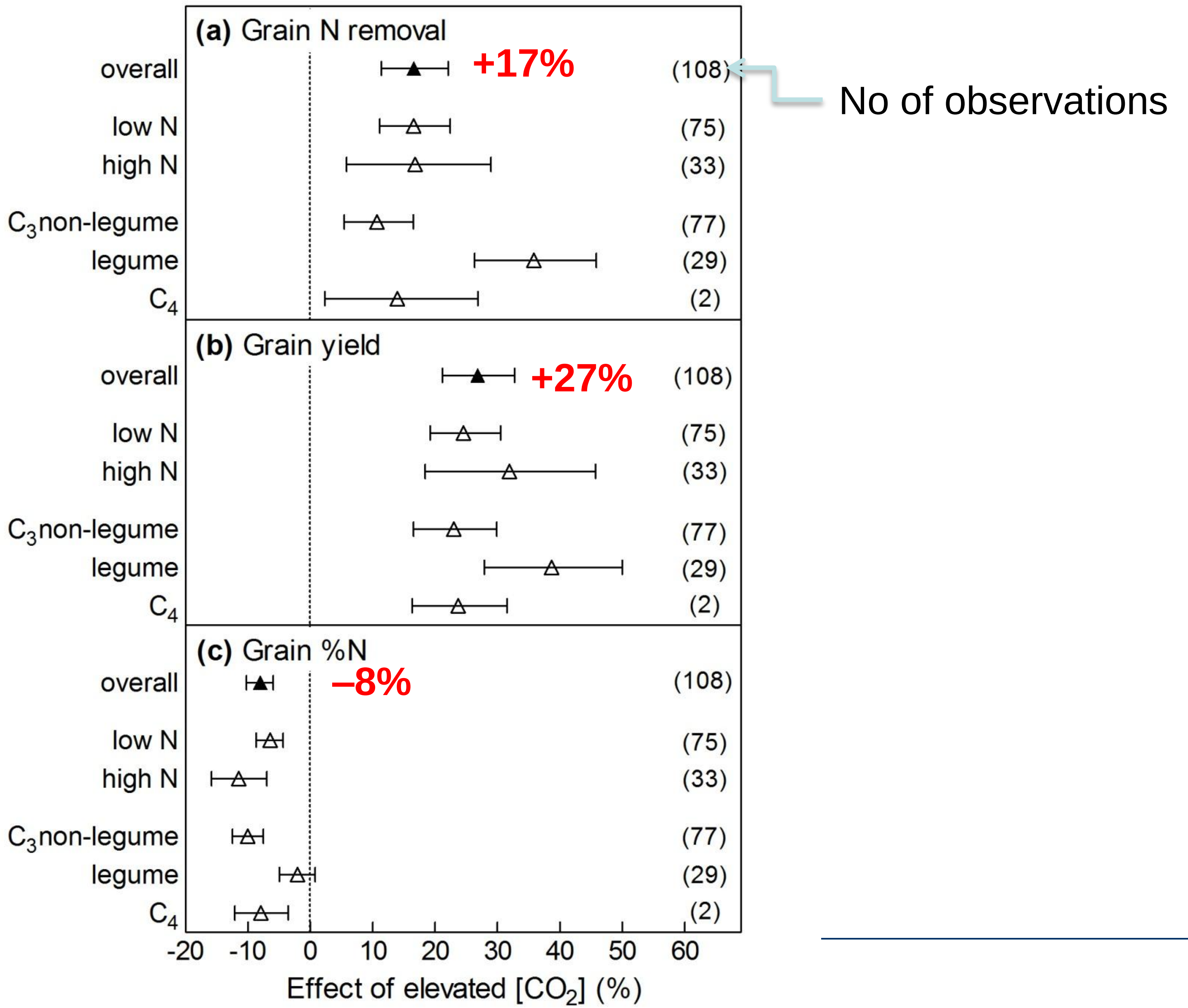
366 observations from 127 studies

Lam et al, 2012, Globe Change Biology, doi: 10.1111/j.1365-2486.2012.02758.x

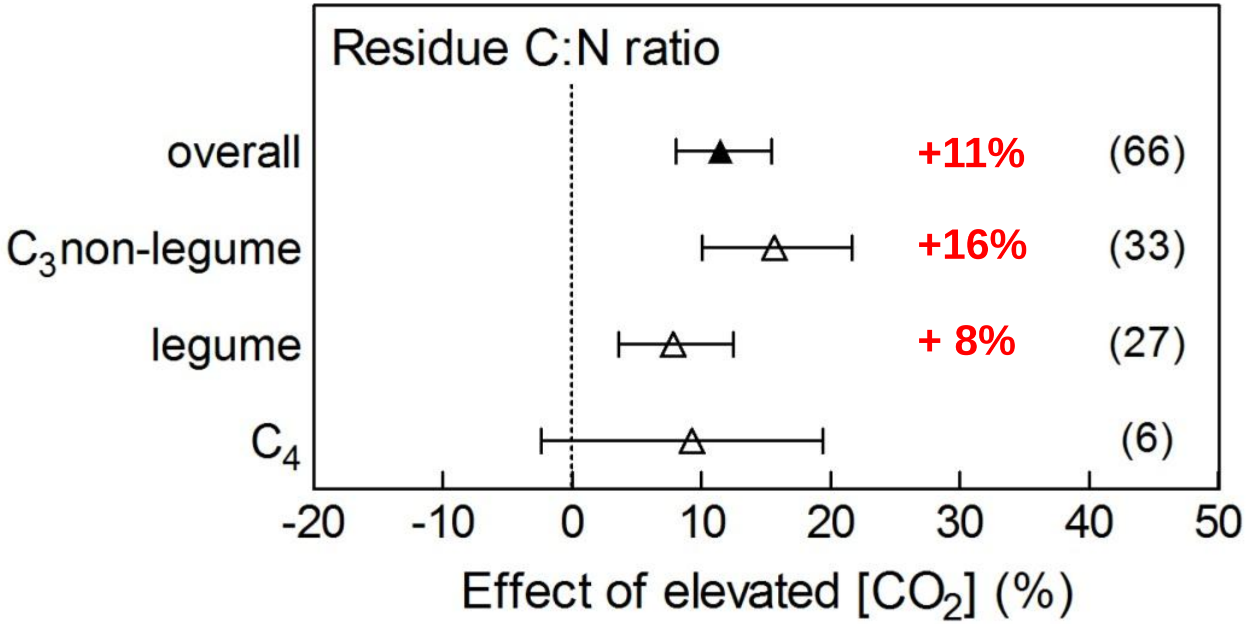
Methods of meta-analysis

- Response metric: natural log of the response ratio (*r* = response at elevated [CO_2]/response at ambient [CO_2])
- Percentage change due to elevated [CO_2]: (r – 1) $\times$100
- Weighting function (by replication)
- Significant [CO_2] effects if the confidence intervals did not overlap with zero.
- Categorical variables: plant functional group (C_3 non-legume, legume or C_4) and legume type (grain legume or pasture legume)
- N input: low (<150kgN/ha) and high (>150kgN/ha)
- MetaWin 2.1

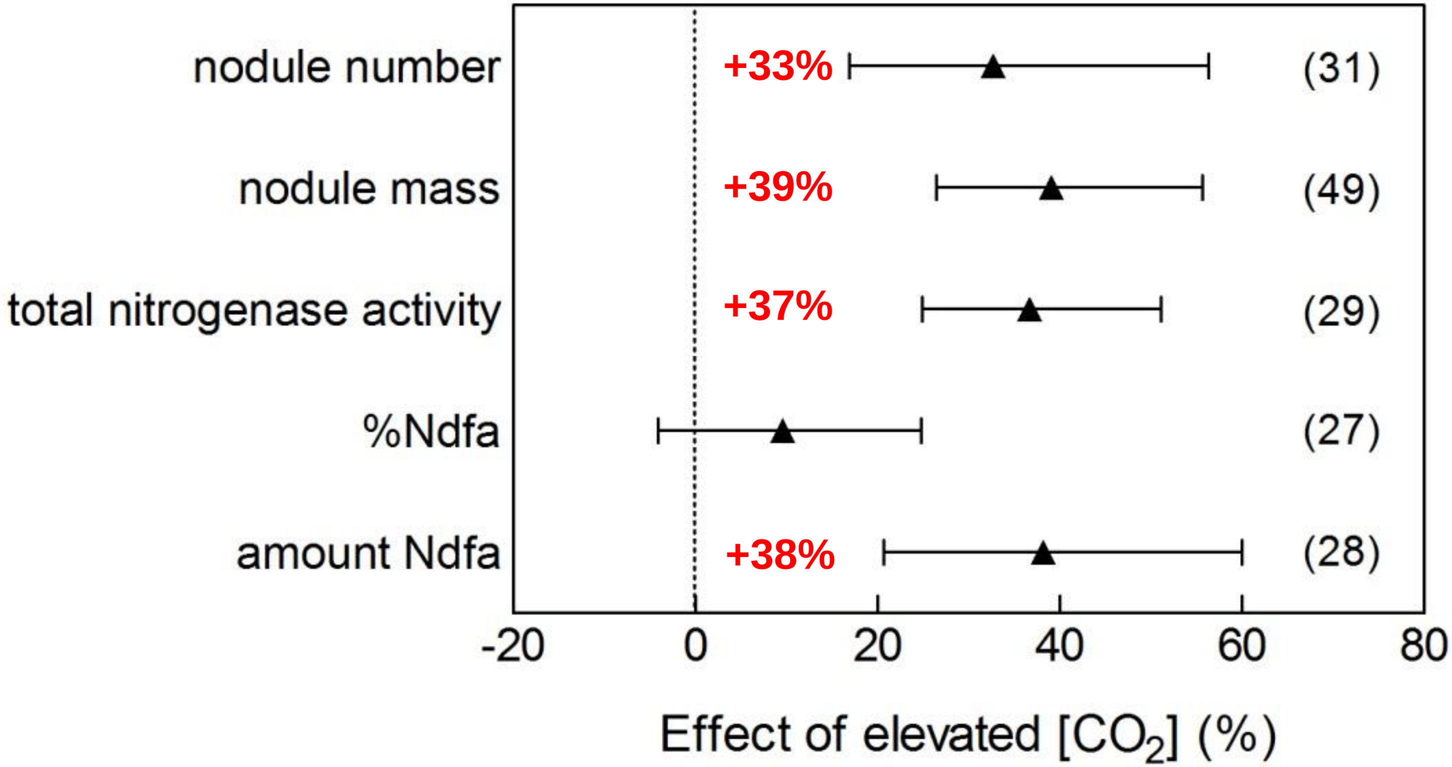
eCO_2 effects on grain parameters



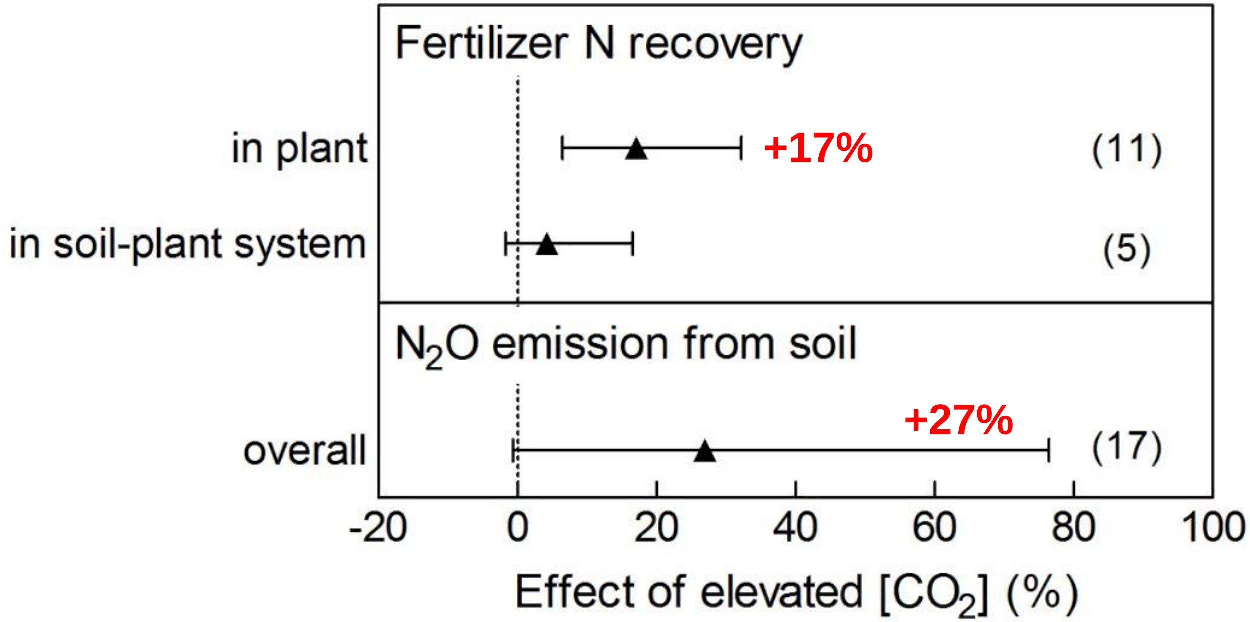
eCO_2 effects on residue C:N ratio



eCO_2 effects on N_2 fixation parameters



eCO_2 effects on fertilizer N recovery and N_2O emission



eCO_2 effects on N budget

$[CO_2]$-induced changes in N budget in various cropping systems

	$[CO_2]$-induced changes in						
	grain N removal (I)		N_2O emission (II)		amount of N fixed (III)		net effect
	mean	95% CI	mean	95% CI	mean	95% CI	(III – I – II)
	kg N ha^{-1} $season^{-1}$						
C_3 non-legume	12.4	4.6 to 20.4	0.22	–0.06 to 0.50	0	NA	–12.6
grain legume	59.6	35.8 to 86.7	0.60	0.13 to 1.06	25.0	5.3 to 53.0	–35.2
pasture legume	0	NA	–0.04	–0.12 to 0.05	53.0	28.3 to 81.1	53.0
C_4	11.8	1.5 to 22.1	0.16	–0.04 to 0.36	0	NA	–12.0

The estimation was made based on the assumption that elevated $[CO_2]$ does not affect ammonia volatilization, N leaching plus runoff, removal by grazing and N deposition. Although predicted shifts in human diets and increasing per-capita consumption from 2000 to 2050 are associated with increased atmospheric N deposition onto global agricultural land (14 Tg yr^{-1}), the increase will be counterbalanced by the corresponding increases in ammonia volatilization (12 Tg yr^{-1}) and N leaching plus runoff (3 Tg yr^{-1}) (Bouwman *et al*. 2011)

Conclusions

- Elevated [CO_2] reduced grain N concentration, but increased N removal in grain cropping systems.
- Extra N will be required to maintain soil N availability and sustain crop yield.
- The extra N could come from increased rates of fertilizer N application, or greater use of legume intercropping and legume cover crops.
- Increase in agricultural greenhouse gas emissions may negate part of the predicted increase in the entire terrestrial C sink.


Thank you.
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