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Soil carbon and nitrogen dynamics following land use change: evidence from stable isotopes

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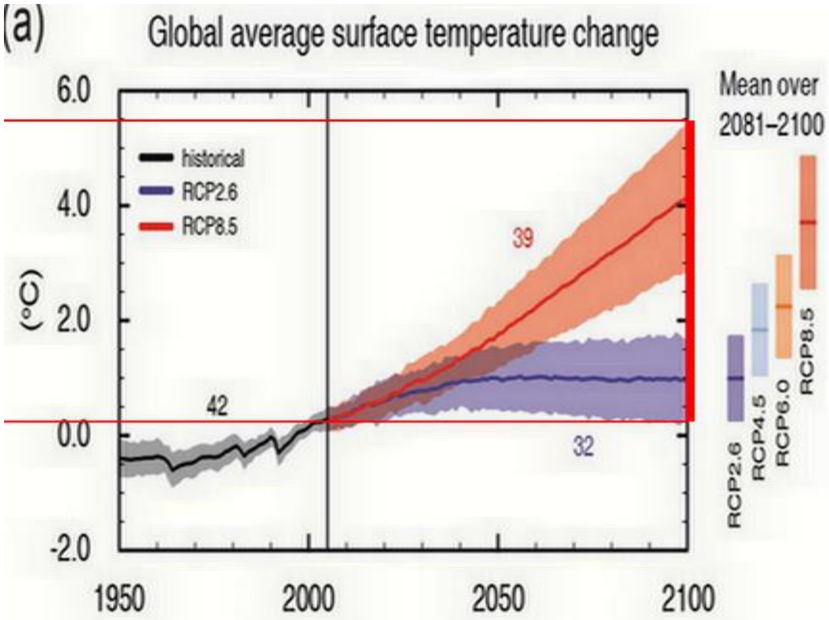
Oct 16, 2017, 南京

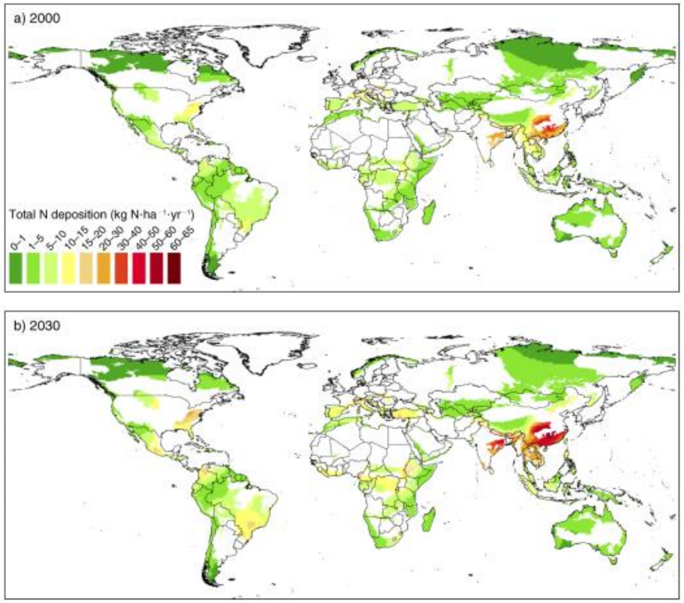
- **Background**
- **Methodology (Carbon and nitrogen stable isotope)**
- **Case studies**

Temperature



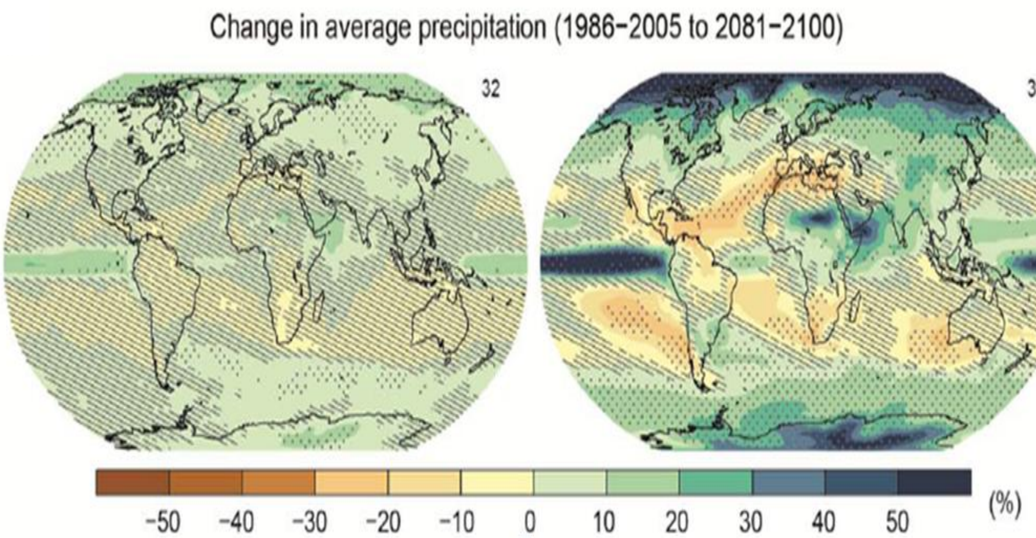
0.5 - 0.9℃ ↑ **1.5 - 3.7℃** ↑

N deposition



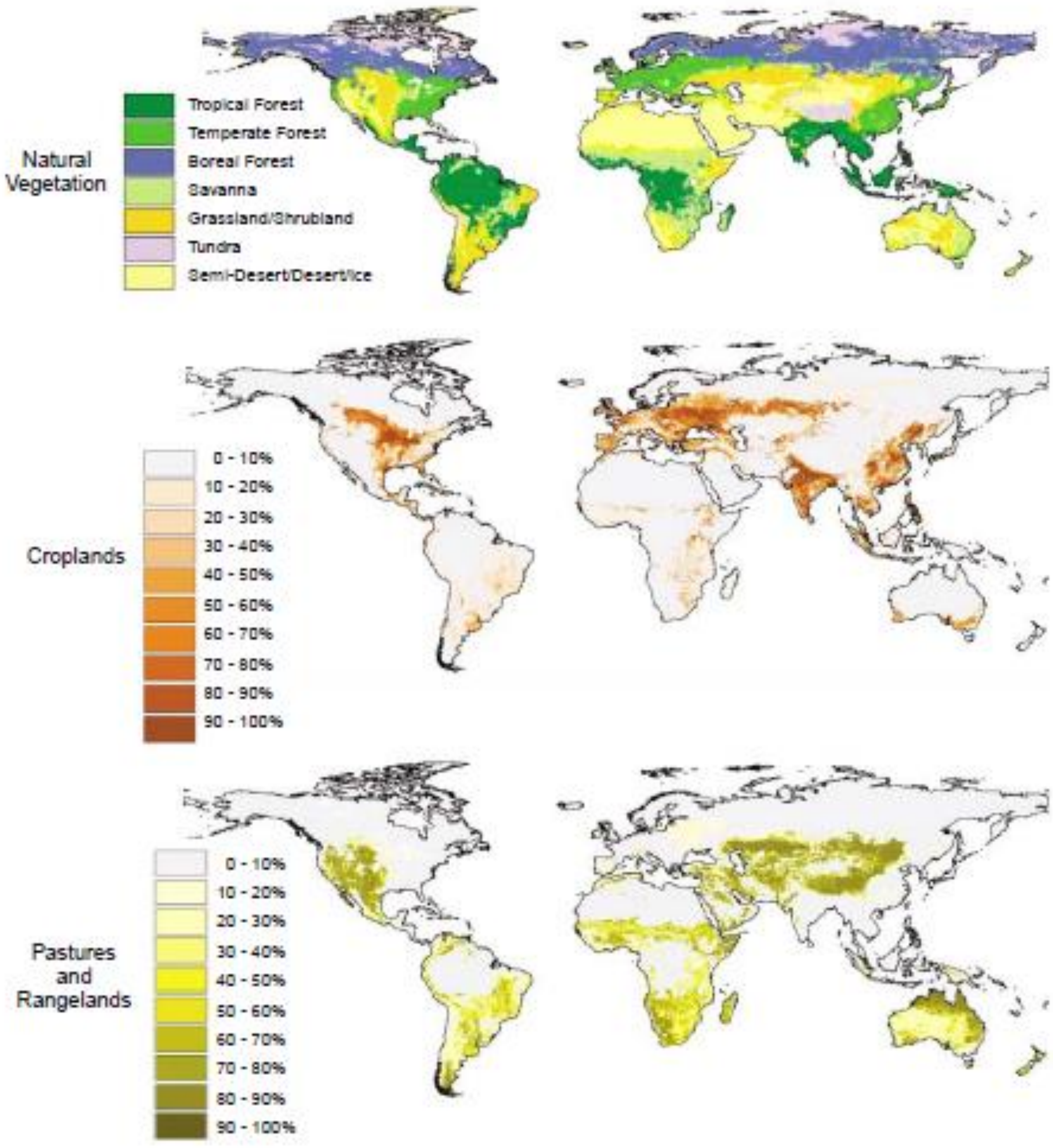
(Bobbink *et al*., 2010)

Precipitation



（IPCC, 2013）

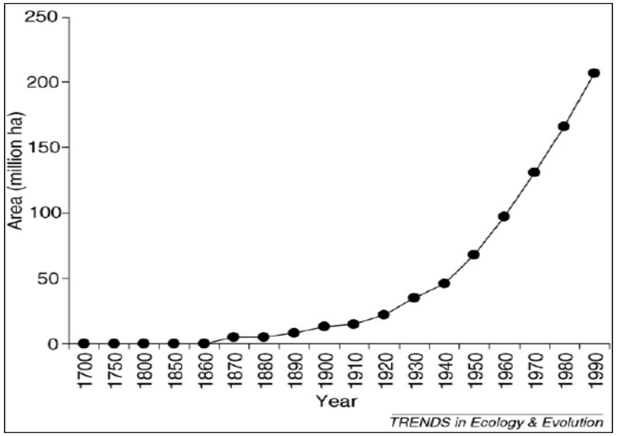
Land use change



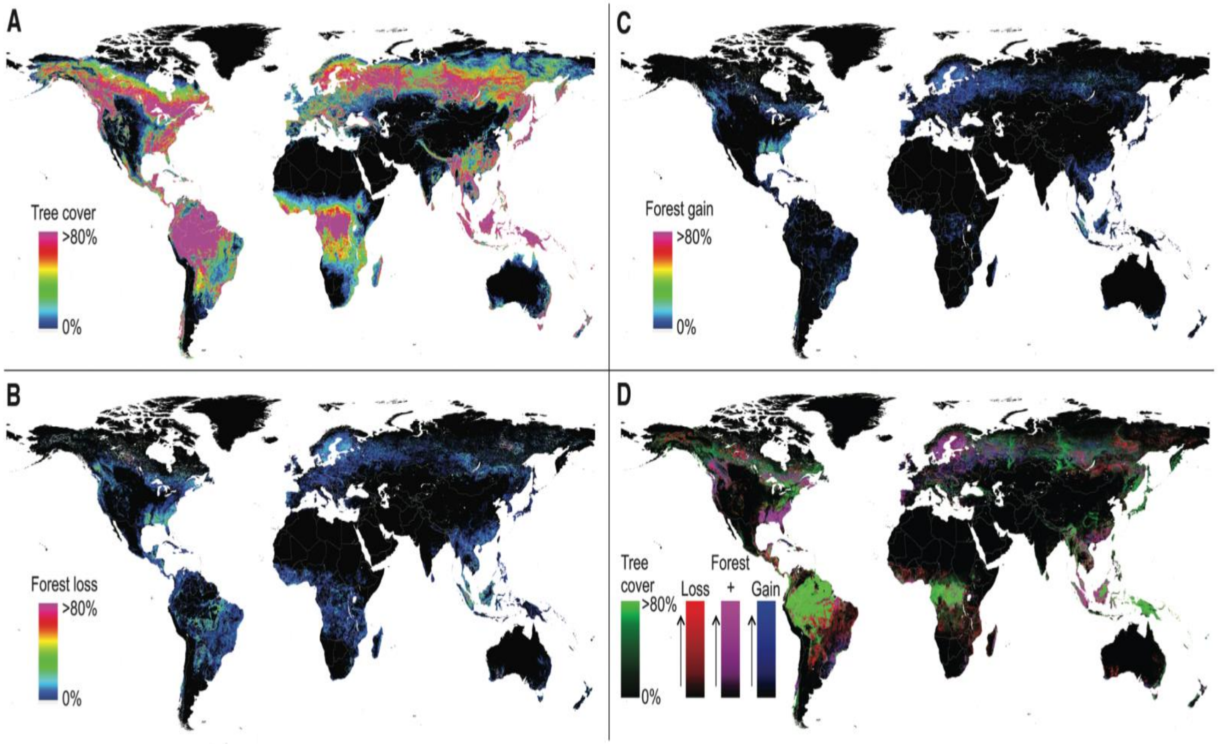
- ✓ **Human activities, especially agricultural activities, have a profound impact on the vegetation and land use patterns worldwide**

（**Foley et al., 2005. *Science***)

Global deforestation vs forest restoration/agricultural reclamation vs abandonment



(Ramunkutty&Foley,1999)



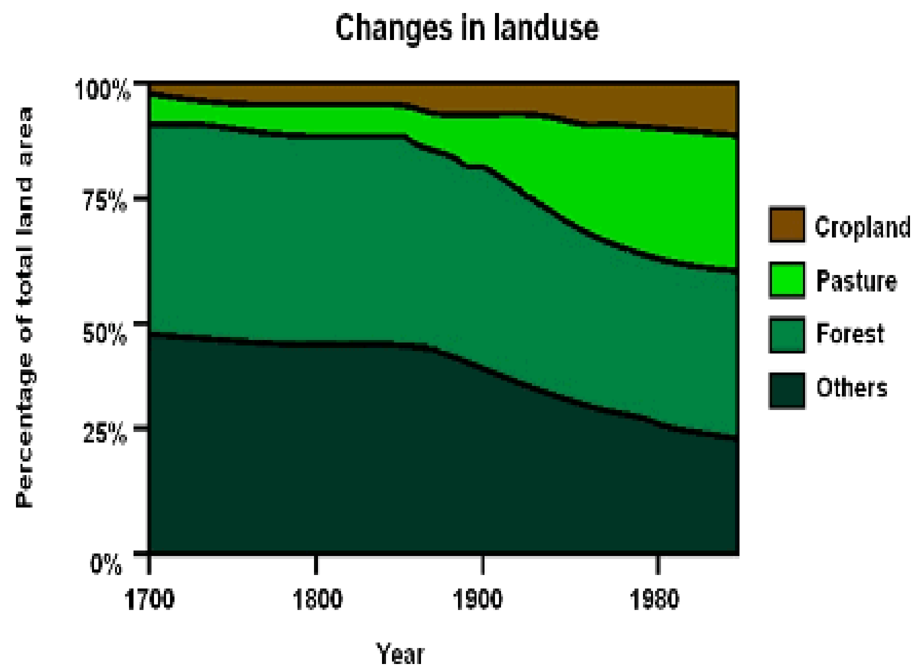
Global forest change since 21th Century

Forest loss: 2.3 million km2

Forest gain: 0.8million km2

(Hansen et al., 2013， *Science*)

Land use change



（Goldewijk and Battjes, 1997）

Forest → cropland: C ↓ 42%

Grassland → cropland: ↓ C 59%

（Guo and Gifford, 2002）

Soil organic carbon pool C: input and output / global change

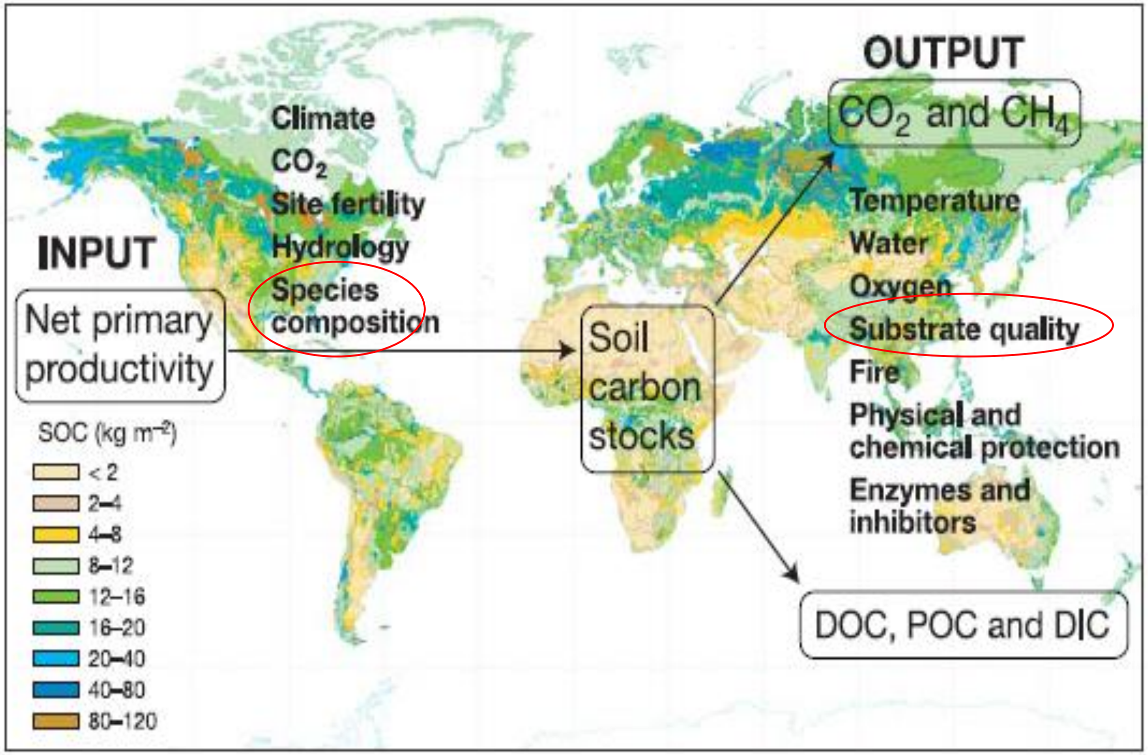
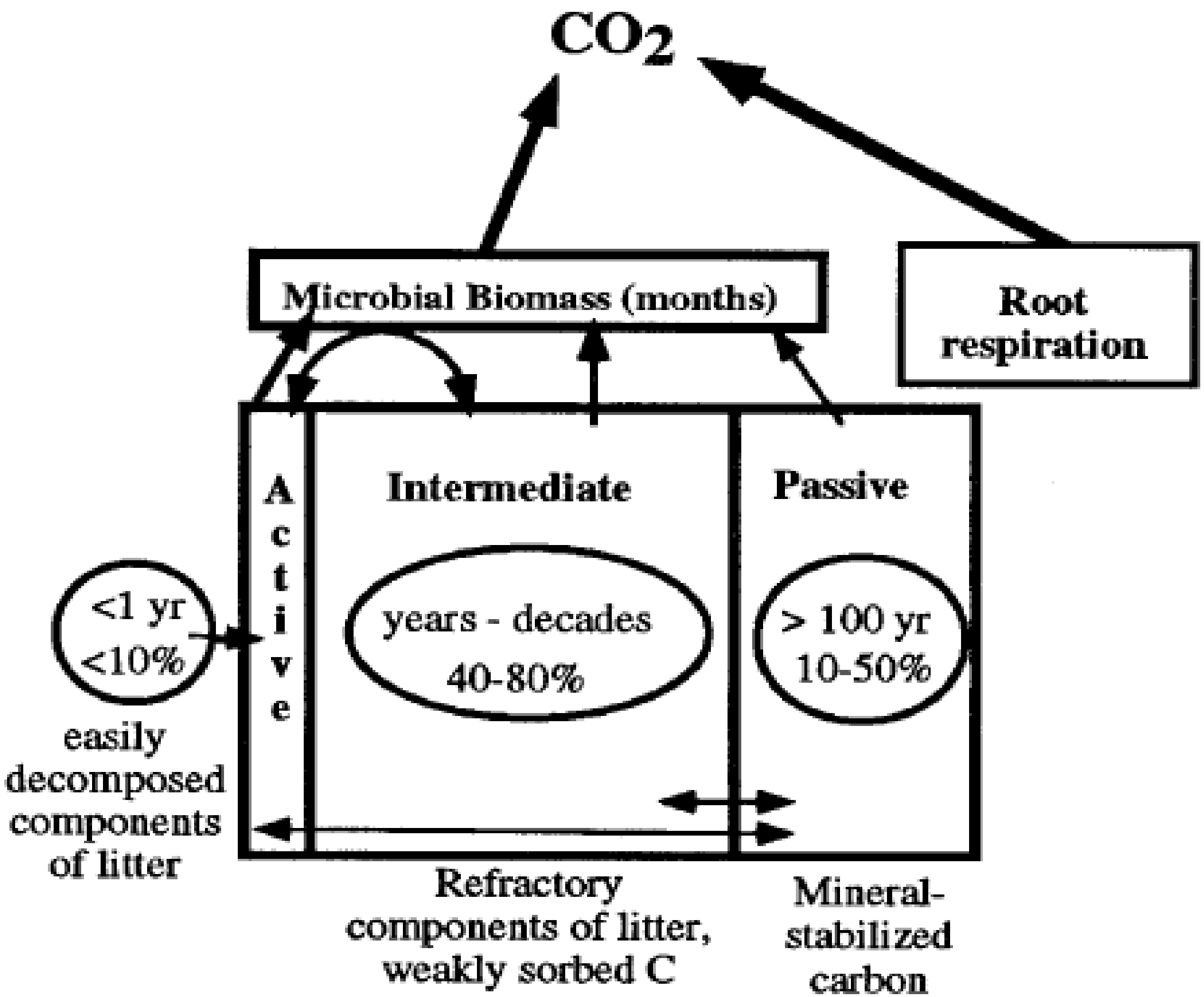


Figure 1 | Diagram of factors controlling the main inputs and outputs of soil carbon, superimposed over a global map of soil organic carbon stocks. While CO_2 is the main product of decomposition in soil, CH_4, dissolved organic carbon (DOC), particulate organic carbon (POC) in water, and dissolved inorganic carbon (DIC) are also significant exports from some soils. The background soil organic carbon (SOC) map (Miller projection; 1:100,000,000) is from ref. 100.

（Davidson and Janssens，2006, Nature）

Soil C fractions and dynamics

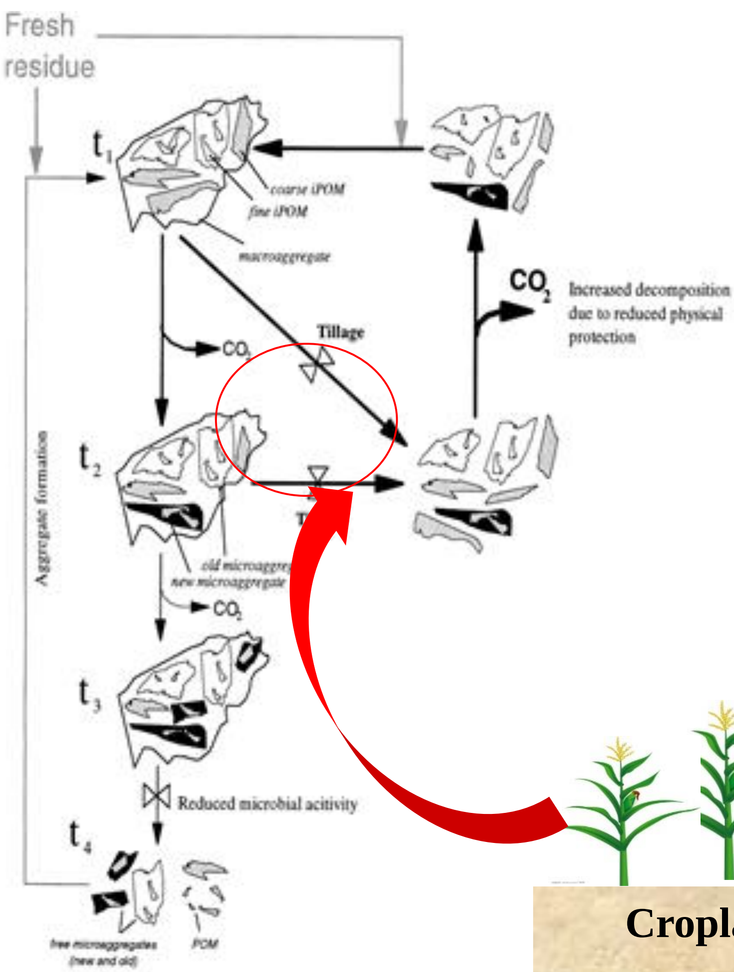


-Active -Slow -Passive C pool

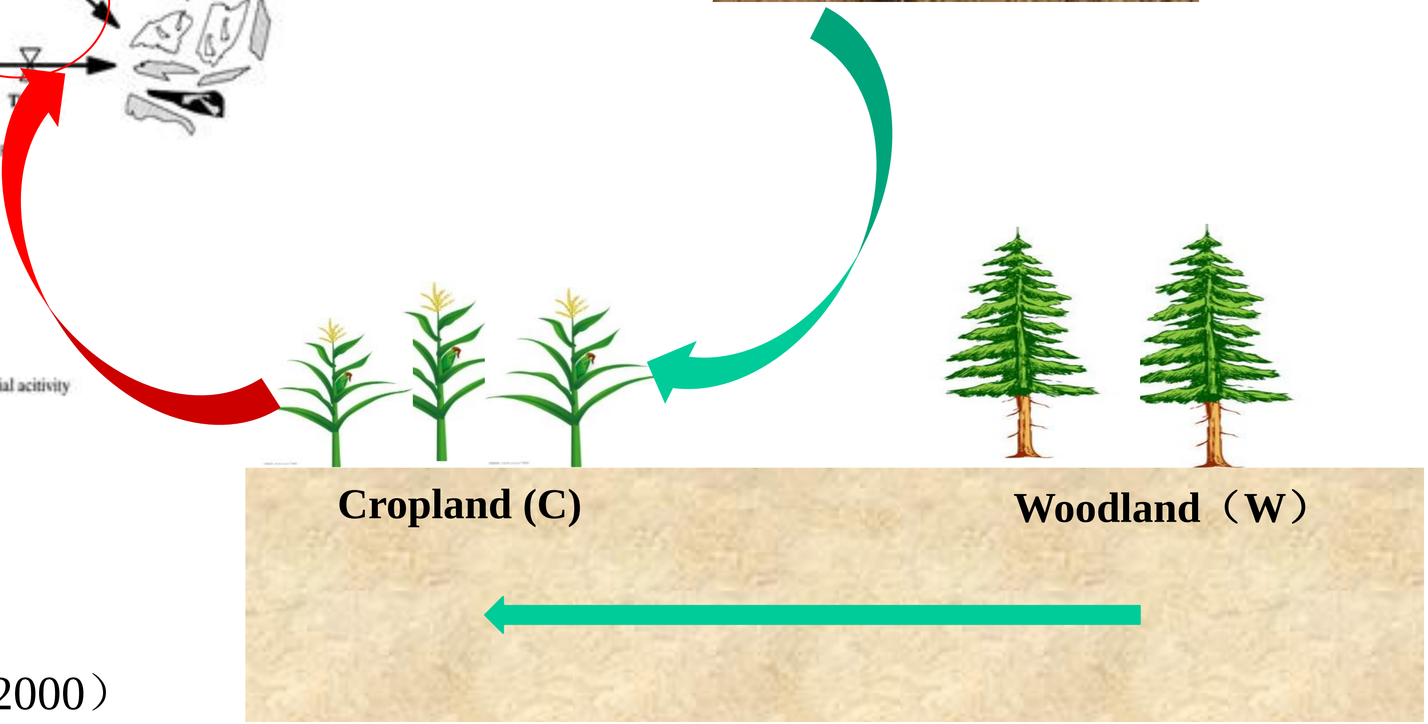
-Labile -Recalcitrant

（Trumbore, 1997, PNAS）

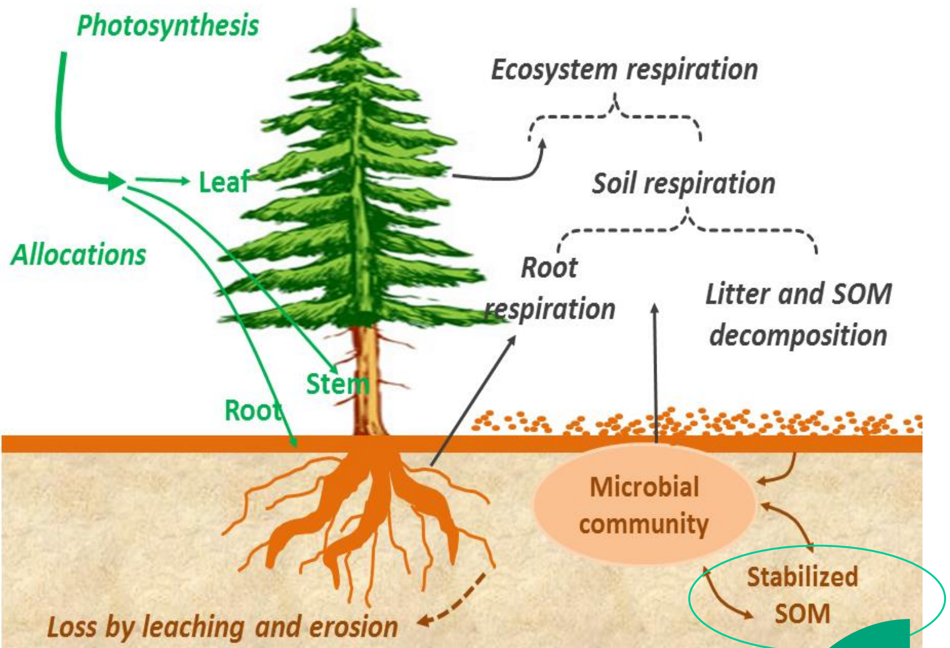
Soil aggregates



（Six *et al*, 2000）

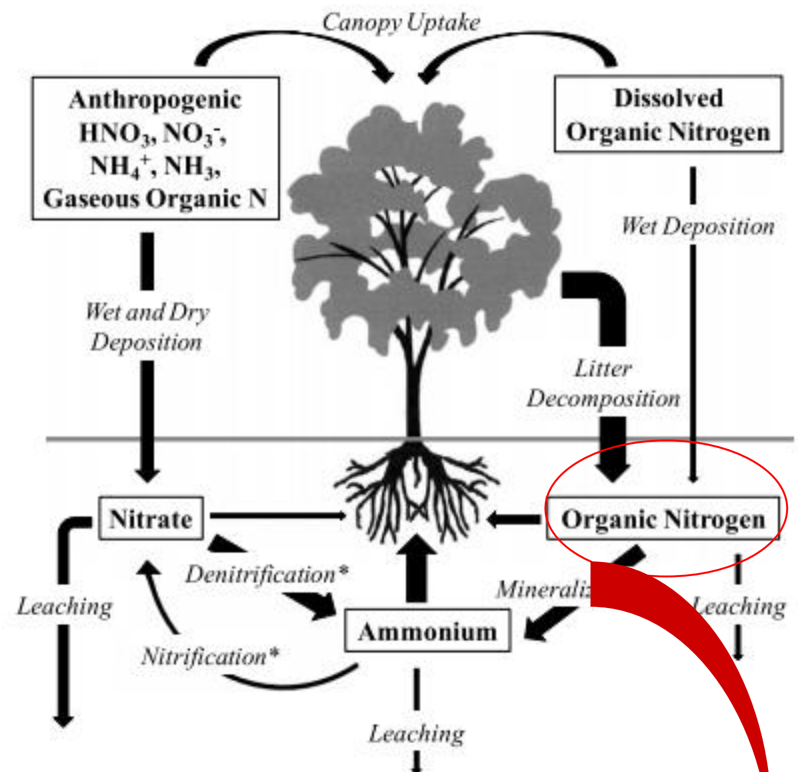


Ecosystem C cycling

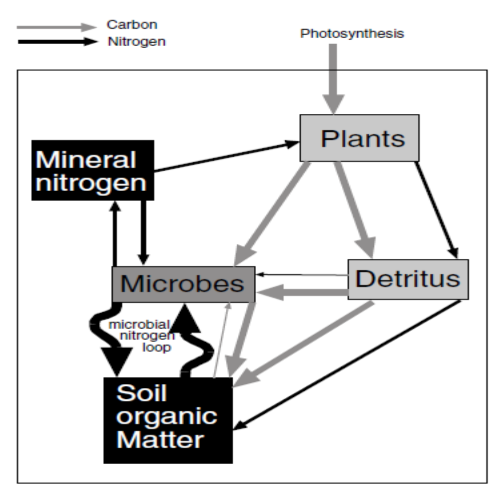


（Trumbore *et al*., 2006）

Ecosystem N cycling



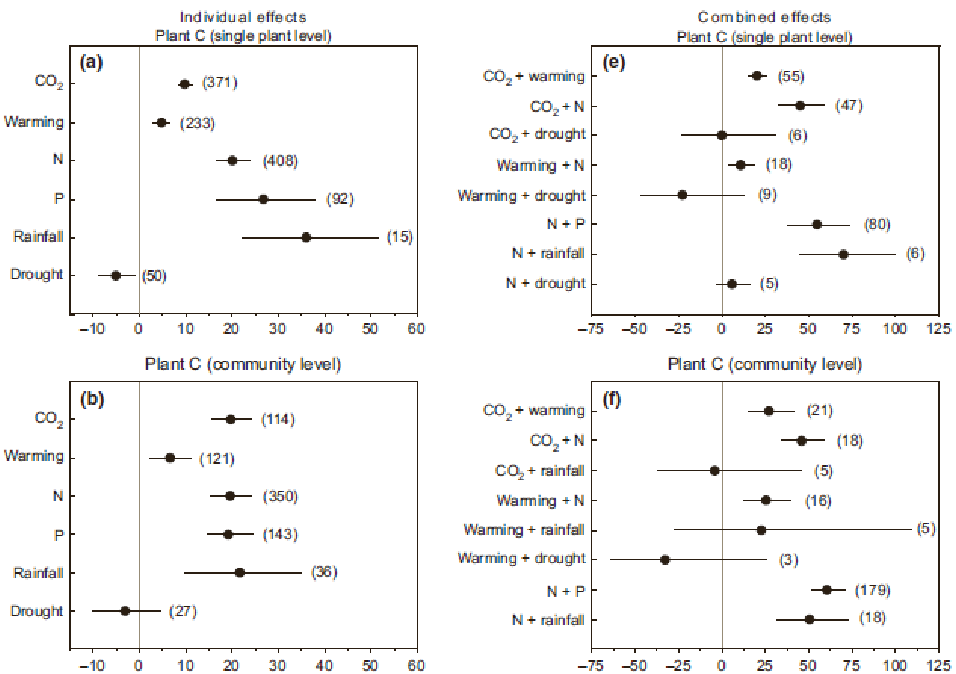
（Costa, 2011）

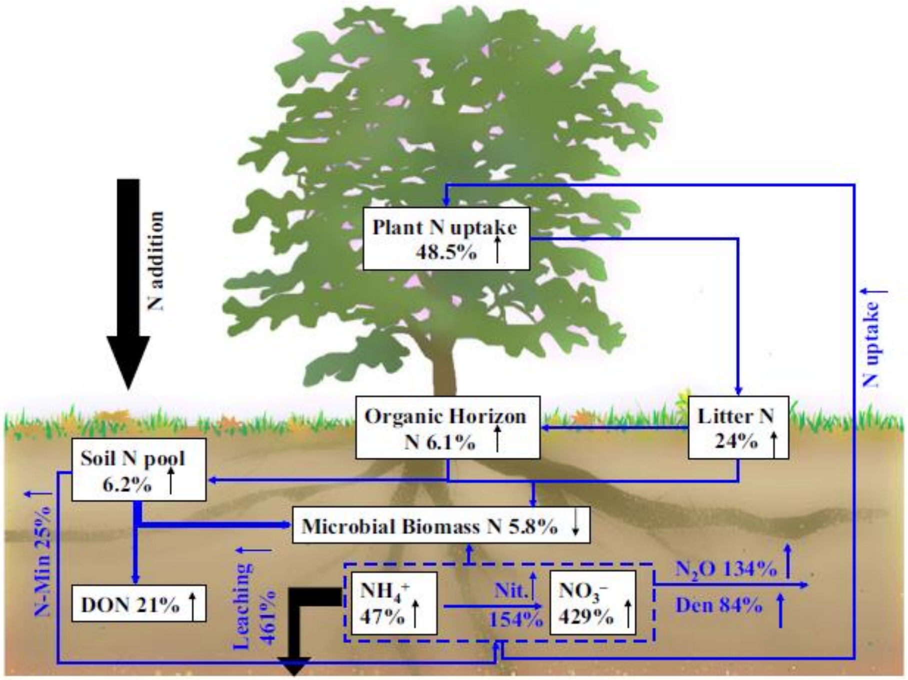


Coupling C and N

（Knops *et al*., 2002）

Global change affects vegetation types, and hence changes litter quantity and quality

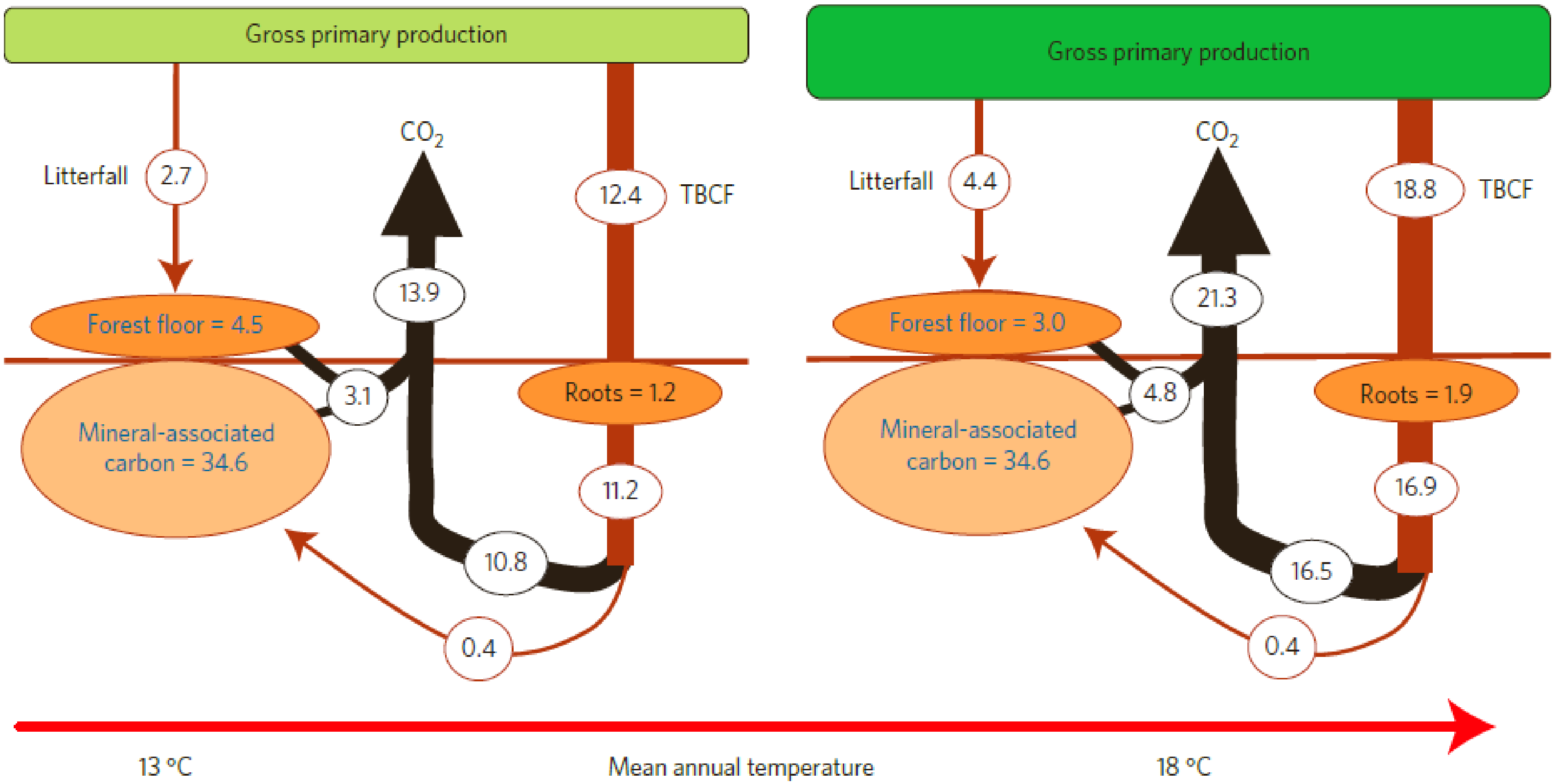




Yue et al., 2017
Ecology Letters

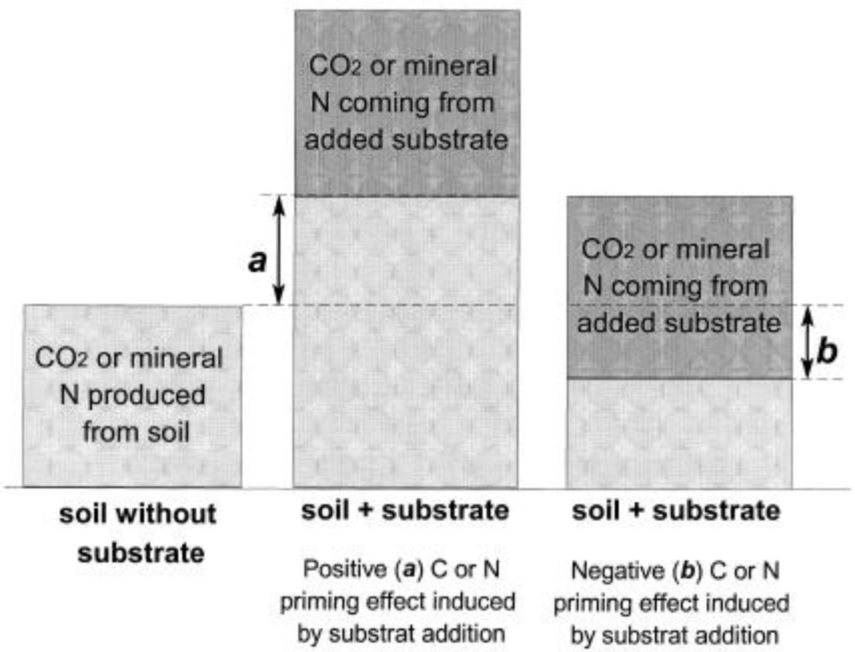
Niu et al., 2016
Ecology Letters

Change in primary productivity (litter input) did not significantly affect soil organic C



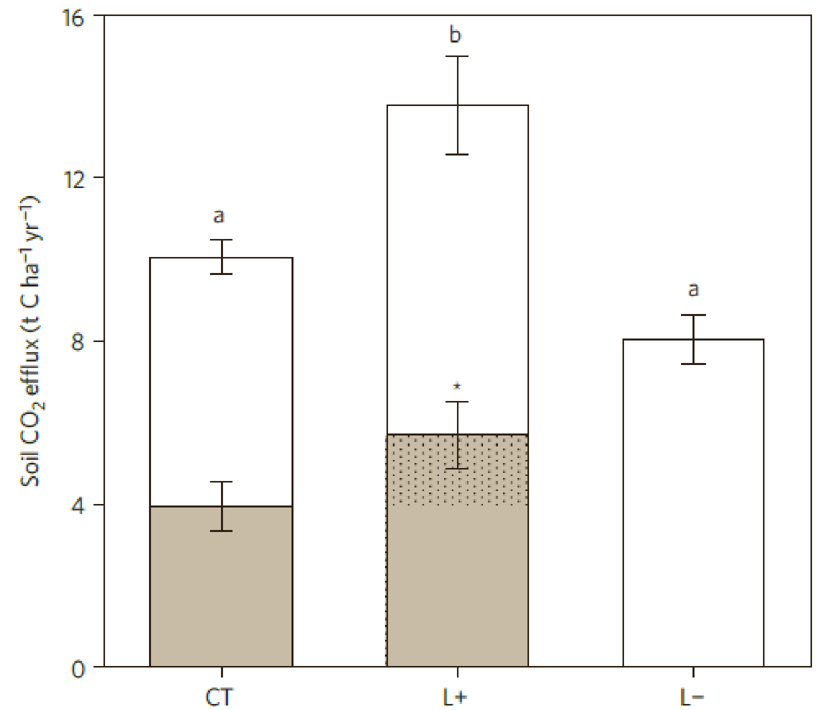
Giardina et al., 2014, *Nature Climate Change*

Increase in litter input results in “priming effect”, leading to decrease in soil organic C



Kuzyakov et al., 2010

Soil Biology & Biochemistry

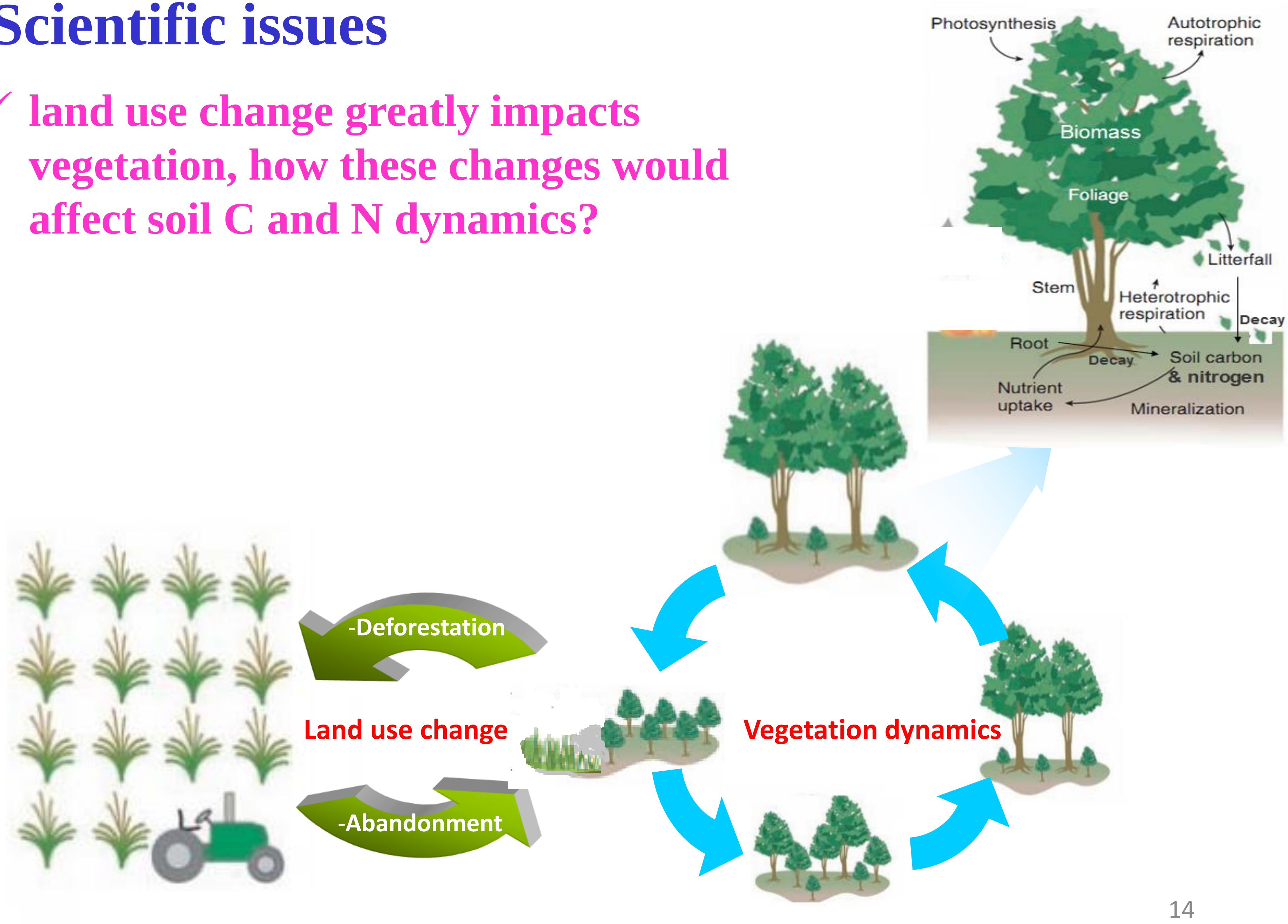


Sayer et al ., 2011

Nature Climate Change

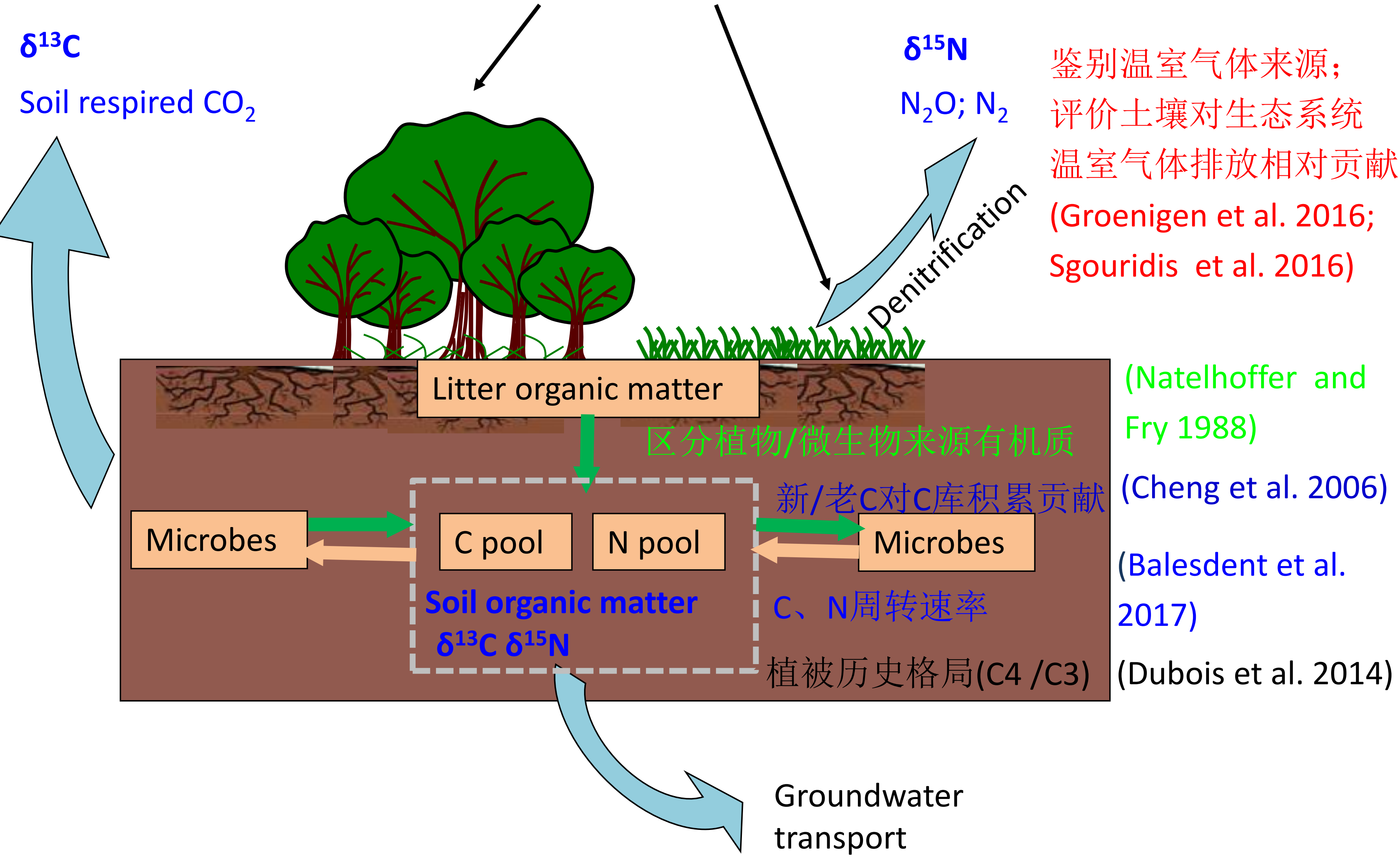
Scientific issues

✓ **land use change greatly impacts vegetation, how these changes would affect soil C and N dynamics?**



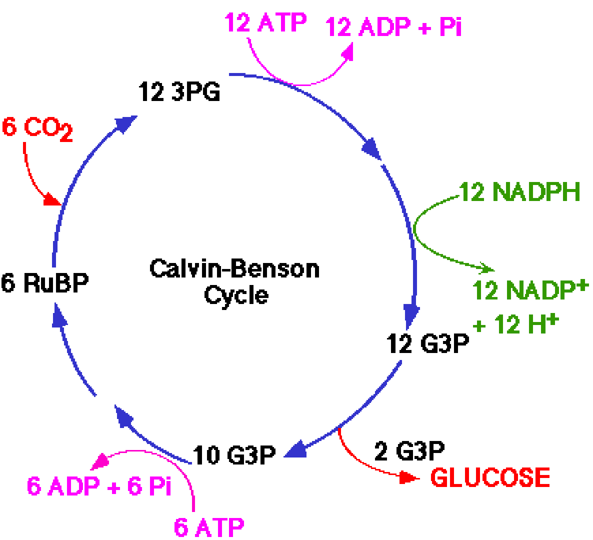
Methodology

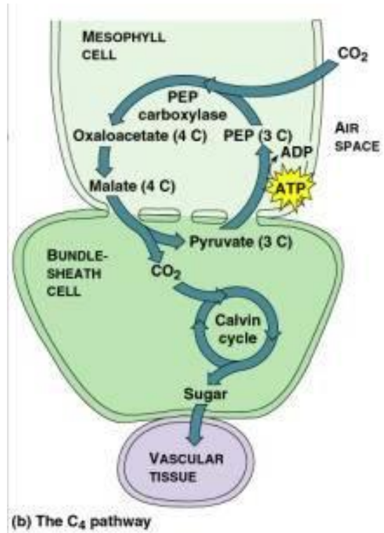
时间、空间变化(Beniston et al. 2014; Yang et al. 2015)
气候变化 (Marcott et al. 2014; Hertzberg et al. 2016)
土地利用变化 (Cheng et al. 2013; Knox et al. 2015)



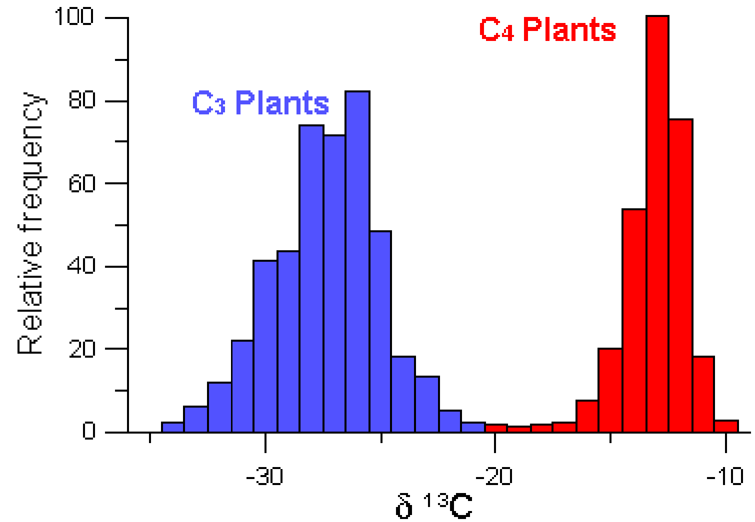
Methodology

Carbon - fixation

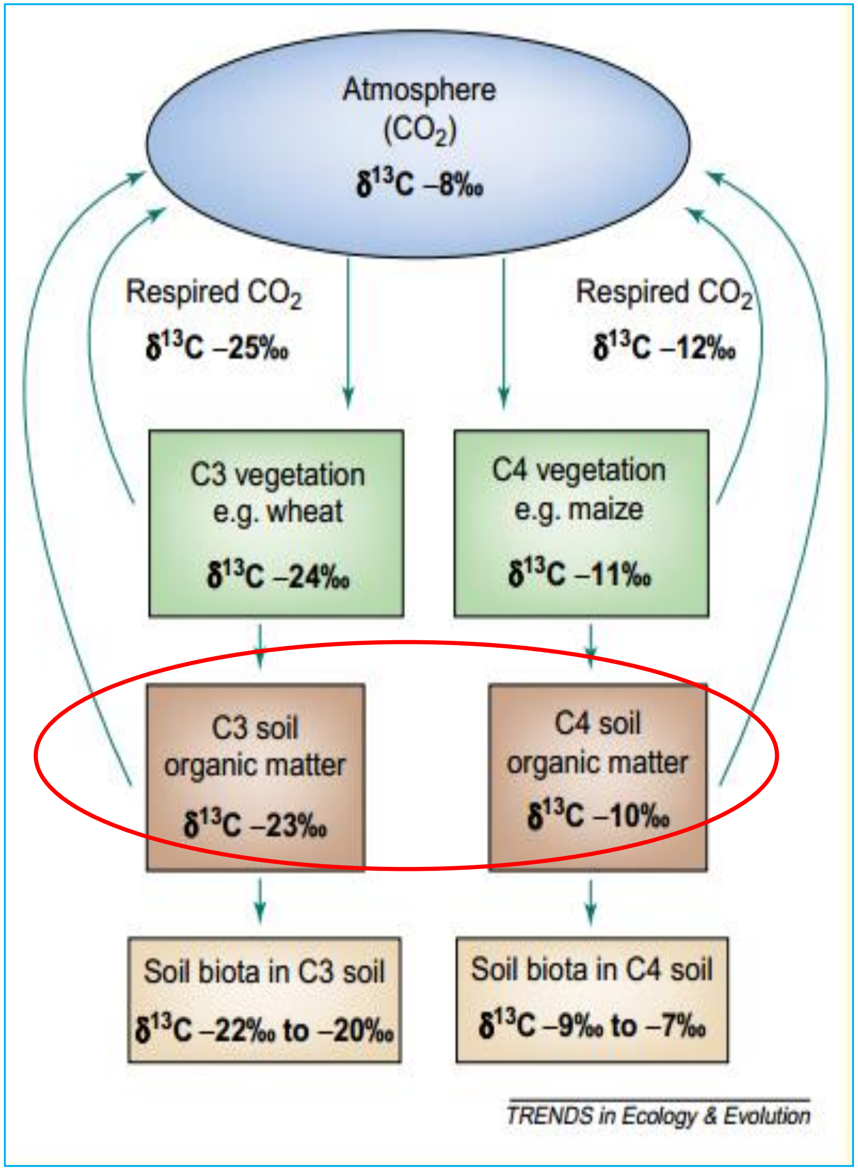




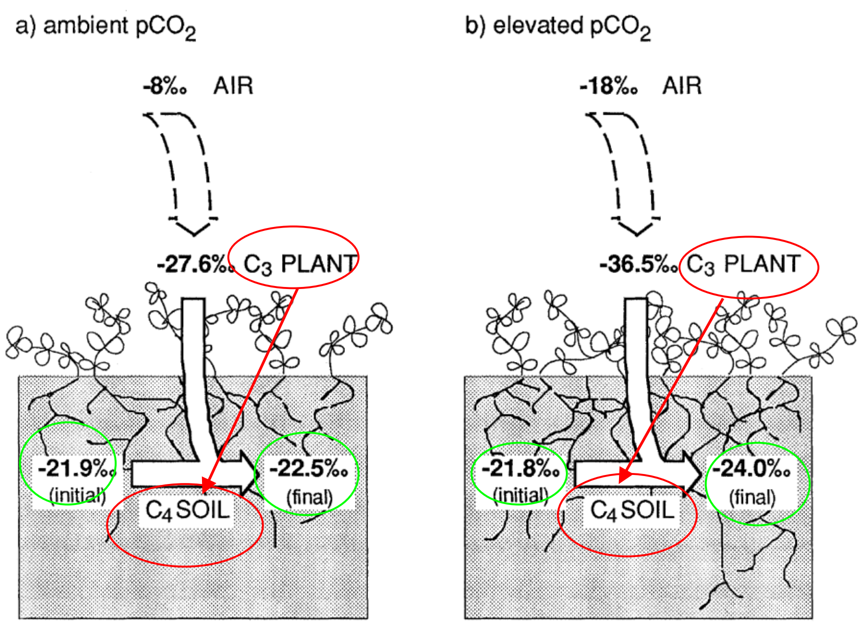
(b) The C_4 pathway



Methodology



（Staddon, 2004）



（Nitschelm *et al*, 1997）

Methodology

linear mixing model:

The carbon and nitrogen isotope ratio of the soil fractions was expressed as:

$$\delta^{\mathrm{h}} X = \left[\left(\frac{X^{\mathrm{h}}}{X^{\mathrm{l}}} \right)_{\mathrm{sample}} \Big/ \left(\frac{X^{\mathrm{h}}}{X^{\mathrm{l}}} \right)_{\mathrm{standard}} - 1 \right] \cdot 1000$$

-The calculation of the proportion (f) of new-derived ××:

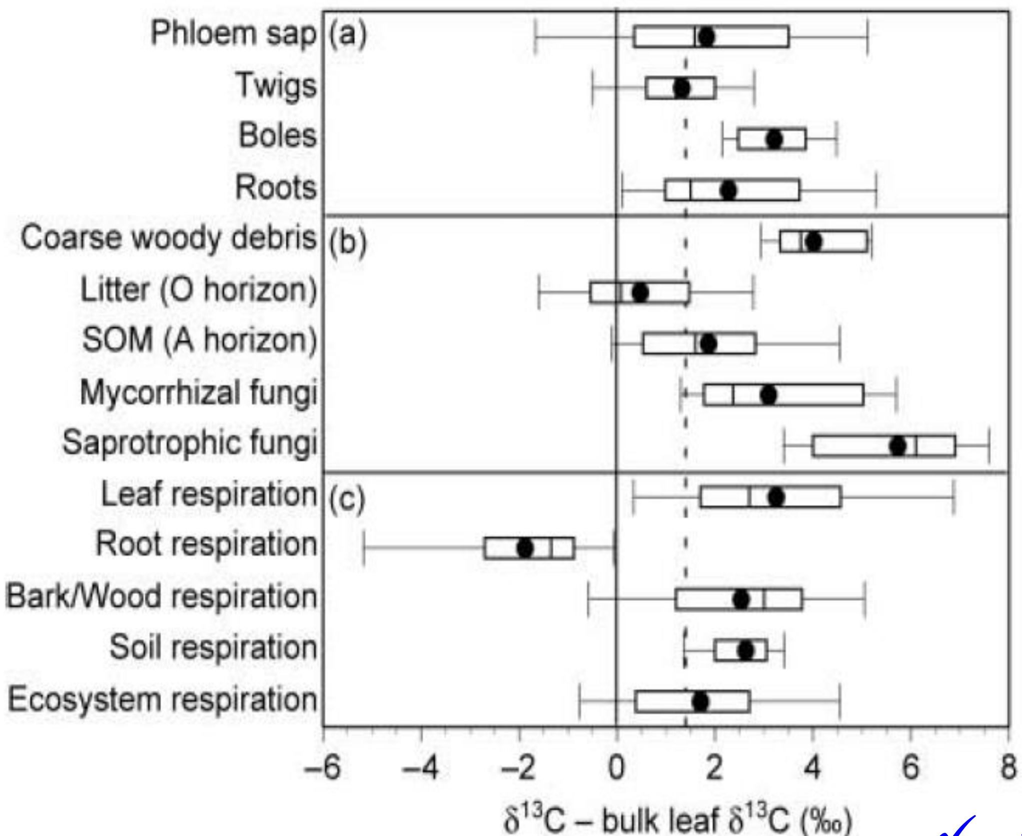
$$f_{new} = \frac{\delta_{new} - \delta_{old}}{\delta_{veg} - \delta_{old}} \times 100\%$$

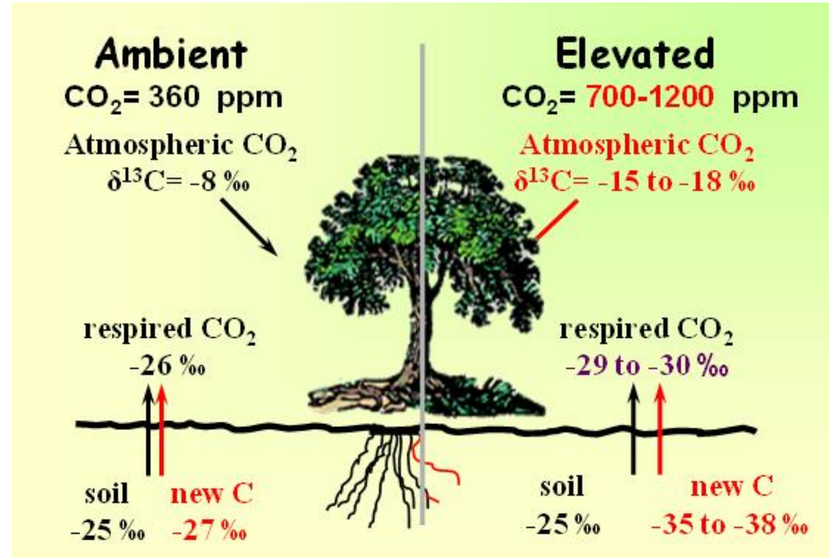
-The turnover rates for whole soil C were calculated using a first-order decay model:

$$k = \frac{-\ln(A_t/A_0)}{t}$$

- (f_{old}=At/Ao； f_{new}=1-f_{old})

Methodology

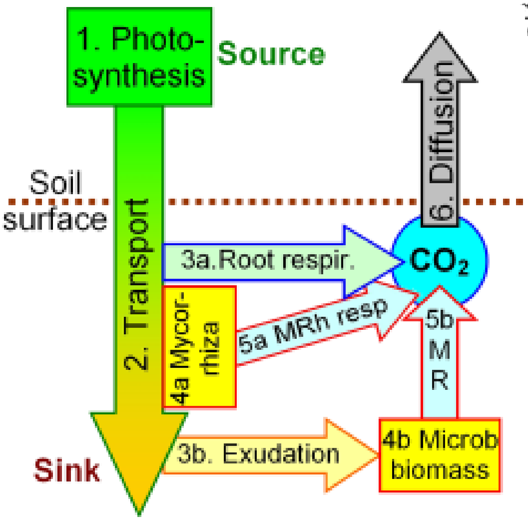


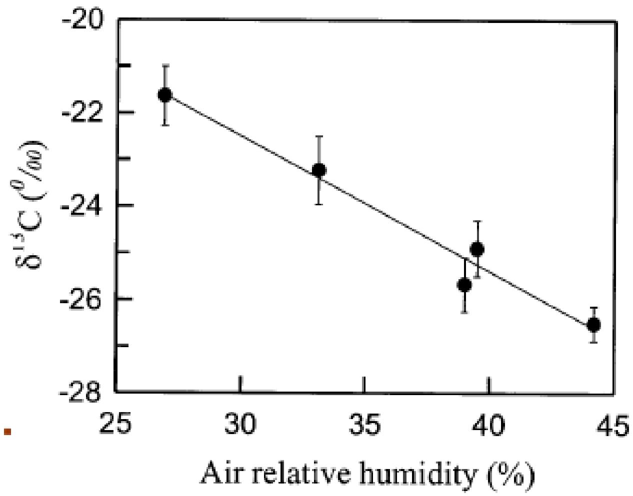


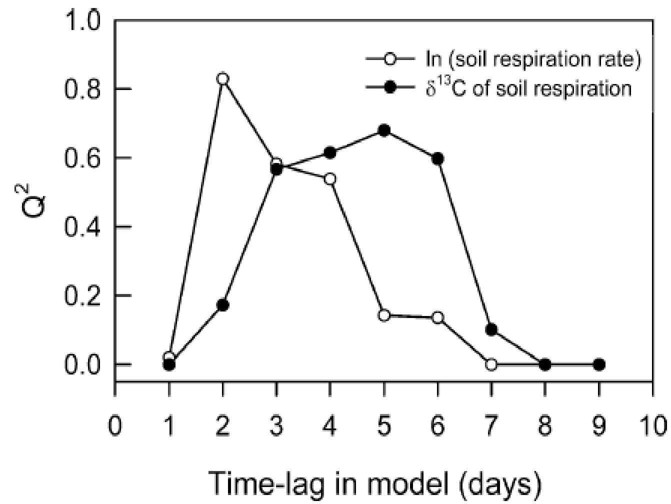
(Bowling et al., 2008)

✓ 土壤呼吸同位素能够反映土壤中一系列物理化学和生物学过程，比如，有机质分解过程中的同位素变化。由此被越来越多的应用到土壤-植被-大气系统碳动态的研究中。

Methodology

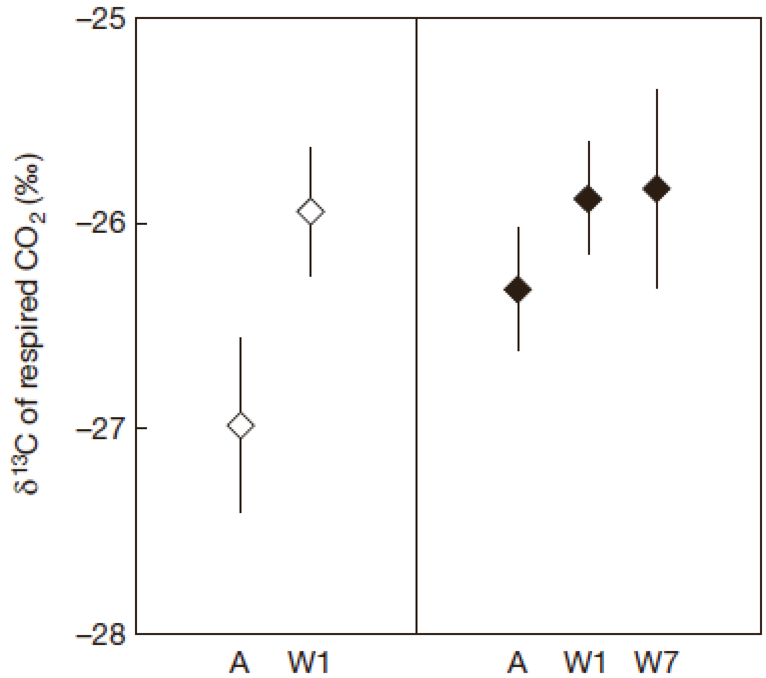






✓ 即便在单一的植被群落中，土壤呼吸的碳同位素值也会发生时间和空间上的变化。研究发现土壤呼吸碳同位素值得变化与1-4天前的空气相对湿度呈显著的相关关系，由此可估算出光合作用产物传递到根际并转换为自养呼吸的速率(Ekblad et al., 2001, 2005)

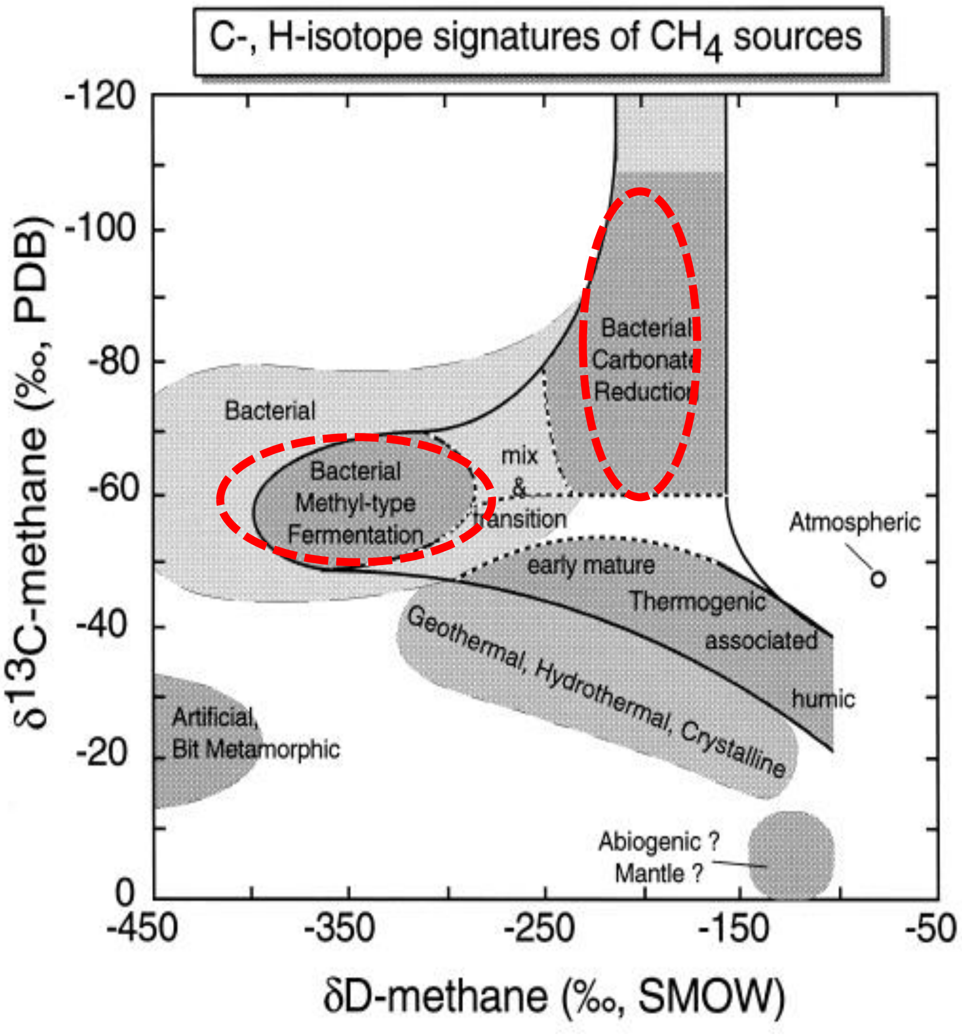
Methodology



(Dorrepaal et al., 2009, Nature)

- 借助土壤呼吸碳稳定同位素可以有效研究新碳、老碳分解速率对全球变化的响应。研究发现升温后，泥炭地土壤呼吸碳同位素值富集，表明底层碳同位素值较高的老碳对土壤呼吸的贡献变大，老碳分解加速 (Dorrepaal et al., 2009；Pries et al., 2015)。

Methodology



- ✓ 甲烷释放主要有两个途径：乙醇发酵(acetoclastic fermentation) 和CO_2还原，前者生产的甲烷同位素值较富集(–65到–50‰)，后者生产的甲烷同位素值高度贫化(–110到–60‰) (Fisher et al., 2017)。

Methodology

- 土壤释放甲烷的碳同位素值 (Fisher et al., 2017):

$$\delta^{13}C = (\delta^{13}C_t \times C_t - \delta^{13}C_0 \times C_0) / (C_t - C_0)$$

- 土壤吸收甲烷过程中的同位素分馏系数:

土壤氧化大气甲烷伴随着动力学同位素效应(kinetic isotope effect,KIE), 即较轻的$^{12}CH_4$比较重的$^{13}CH_4$先被氧化，进而发生同位素分馏。同位素分馏系数α_{soil}计算方法:

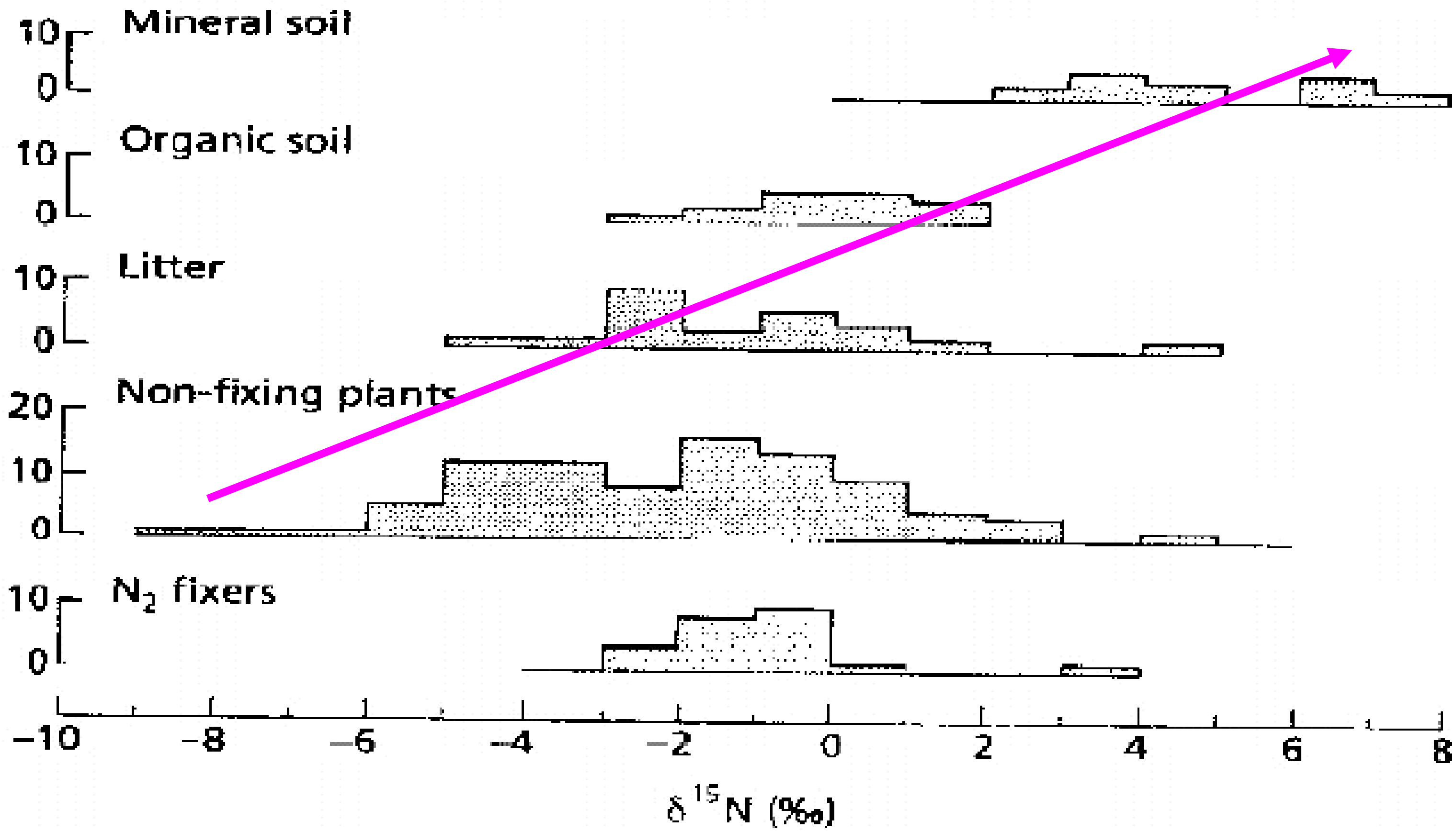
$$\frac{1}{\alpha_{soil}} = \frac{\ln\left(\frac{\delta_t+1000}{\delta_0+1000}\right)}{\ln\left(\frac{C_t}{C_0}\right)} + 1$$

其中，C_0和C_t分别为初始状态和t时刻，静态箱内甲烷的浓度;

δ_0和δ_t分别为初始状态和t时刻甲烷的碳同位素值。

Methodology

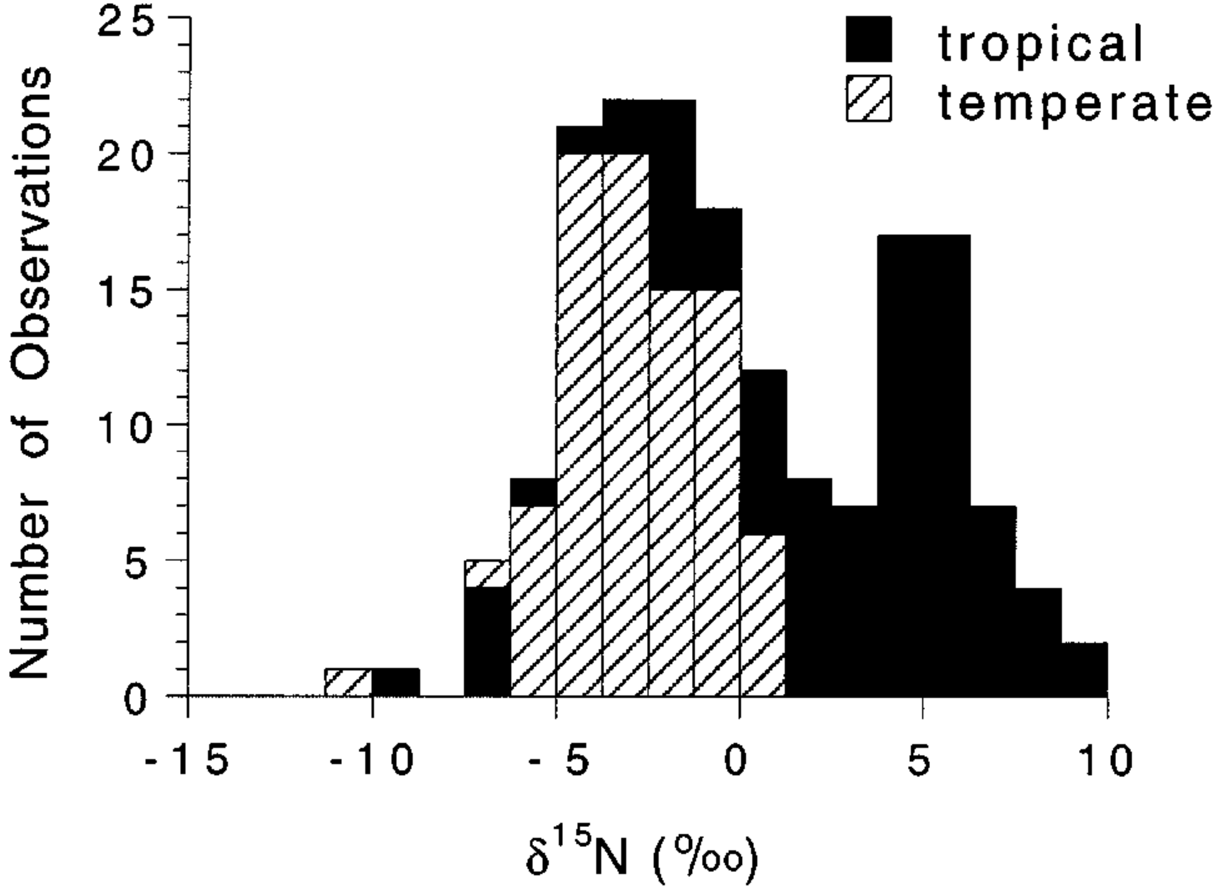
Variation in N isotope Ratios



（Naddelhoffer and Fry, 1994）

Methodology

Nitrogen stable isotopic composition of leaves and soil: Tropical versus temperate forests

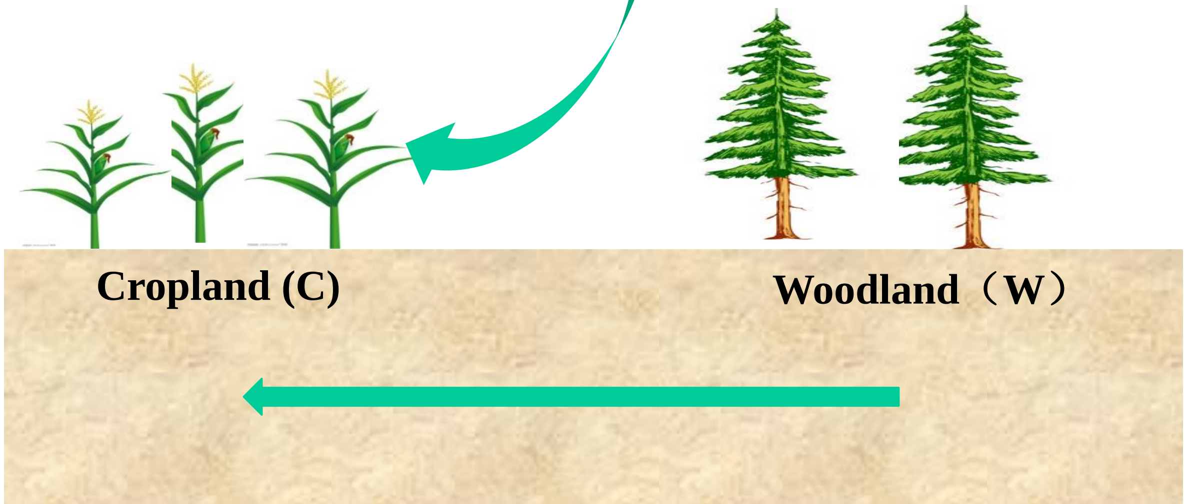


(Martineli et al., 1999)

Methodology

- ✓ Soil δ^{15}N values reflect the net effect of N-cycling processes as influenced by land use
- ✓ Land use and land cover types associated with N losses such as low nutrient input cropping, tend to be enriched with δ^{15}N

Awitti et al., 2008



-δ

Methodology

Isotope mixing model

$$F_A + F_N = F_U + F_D + F_L, \qquad [1]$$

$$F_D = \left[(F_A + F_N) \times (\delta^{15}N_{soilNO3-} - \delta^{15}N_{NO3\text{-}input} - \varepsilon_U) + F_L \times \varepsilon_U \right] / (\varepsilon_D - \varepsilon_U). \qquad [7]$$

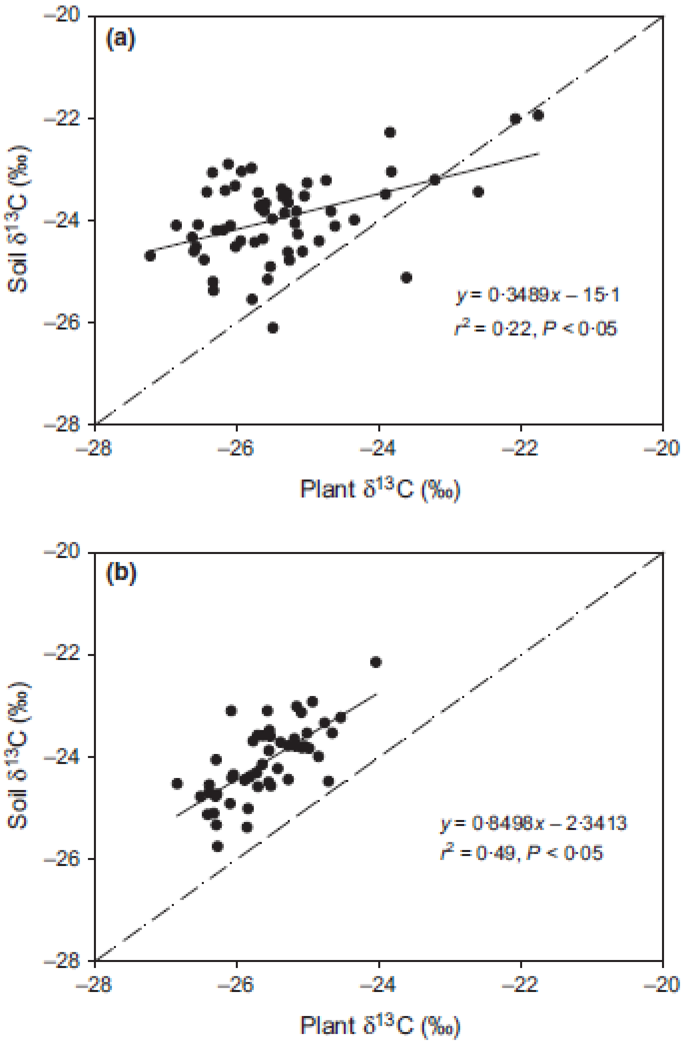
- F_A, F_N, F_U, F_D, and F_L represent annual NO_3^{-1} fluxes of atmospheric deposition, soil gross nitrification, plant or microbial gross uptake, denitrification, and leaching, respectively

- The abbreviations ε_D and ε_U denote isotope effects ($e = {}^{14}k/{}^{15}k - 1$, reported in‰, with k being the rate constant) by denitrification and biological NO_3^{-1} uptake

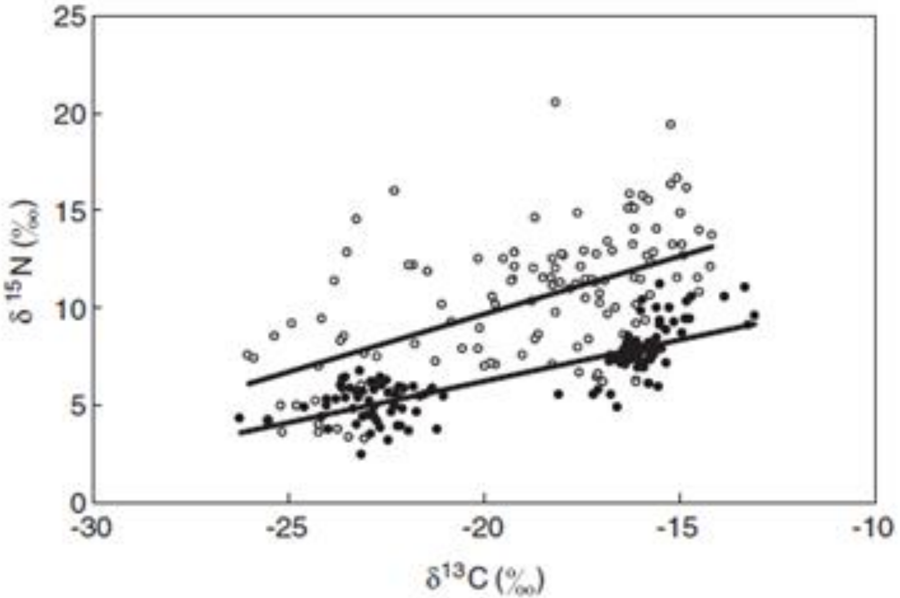
✓ **Microbial denitrification dominates nitrate losses from forest ecosystems**

Fang et al., 2015

Methodology

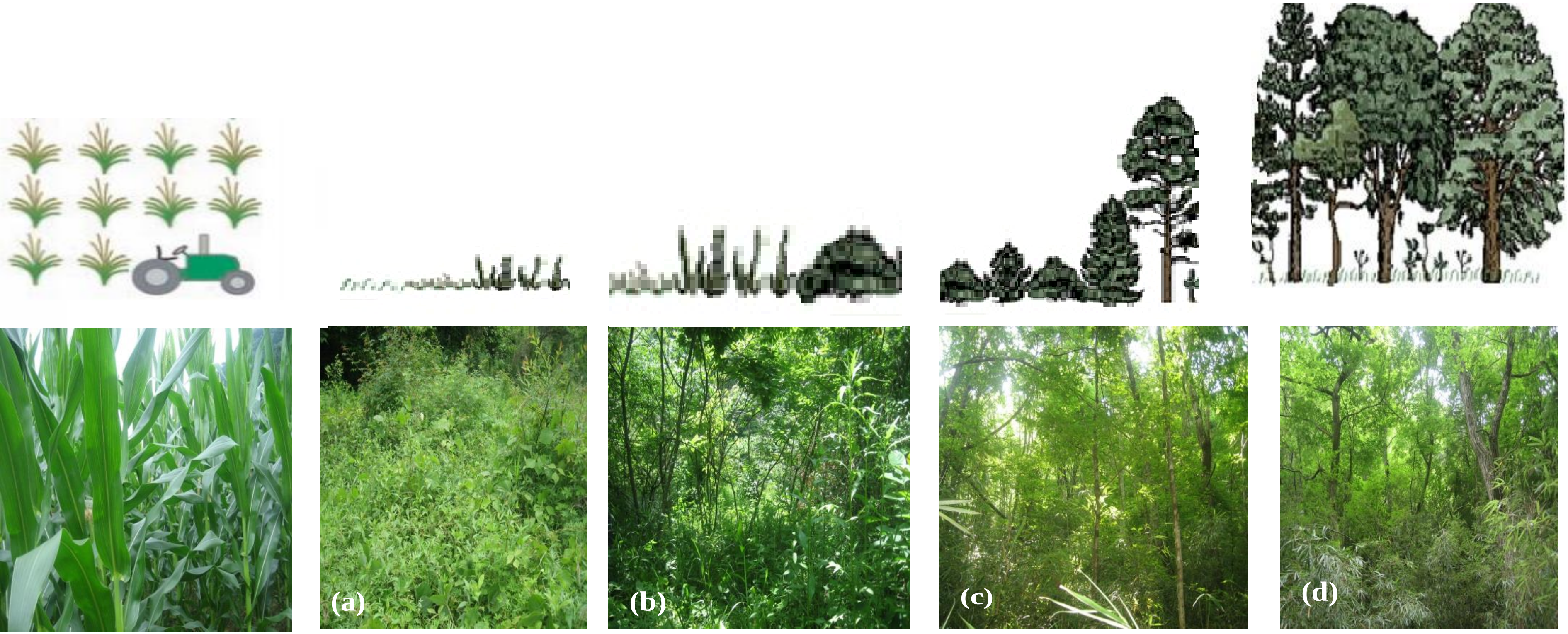


（Yang et al., 2015）



（Dijkstra et al., 2006）

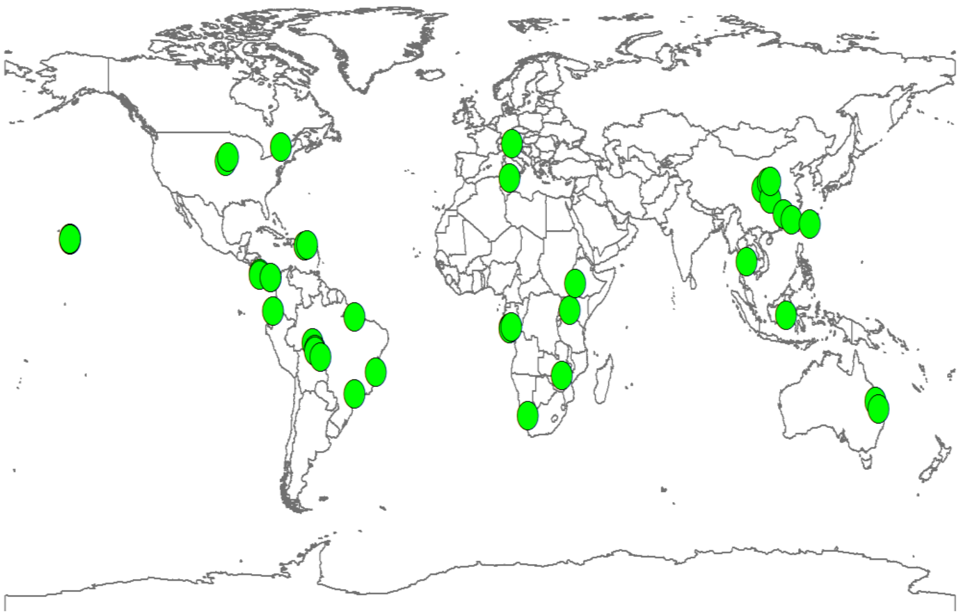
Case study I: Soil C dynamics following land-use change varied with temperature and precipitation gradients

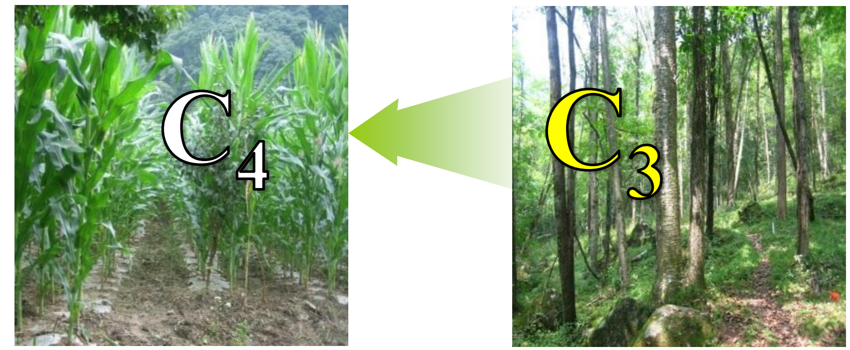


耕地 → 草地 → 灌丛 → 中幼龄林 → 成熟林

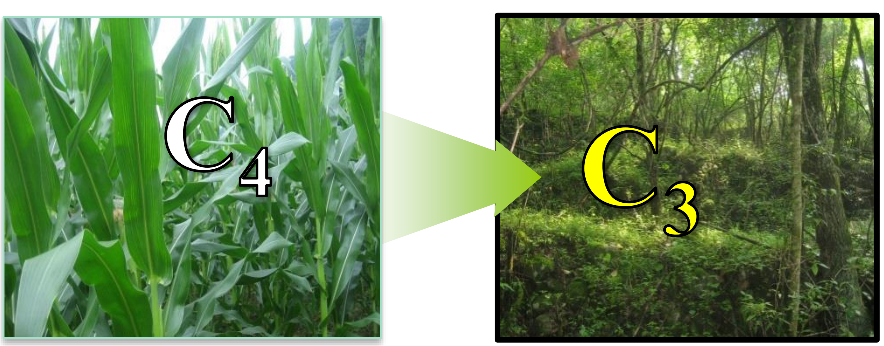
C_4 → C_3，采集了植被、土壤有机碳的稳定同位素数据。

(Zhang *et al.* 2016 *Global Change Biology*)

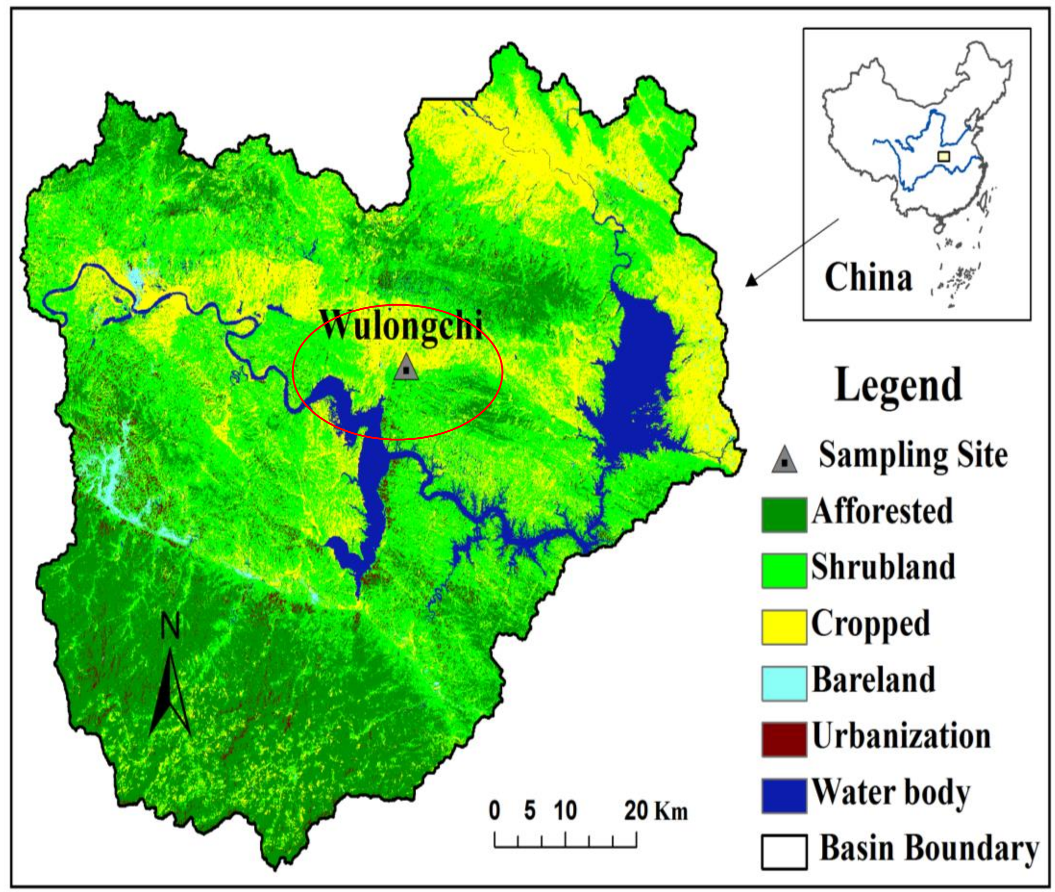




- 131 sites (87 deforestation observations and 44 reforestation)
- The dynamics of new and old C following land use change
- The relationships between soil organic C (SOC) decomposition rates and climatic factors.



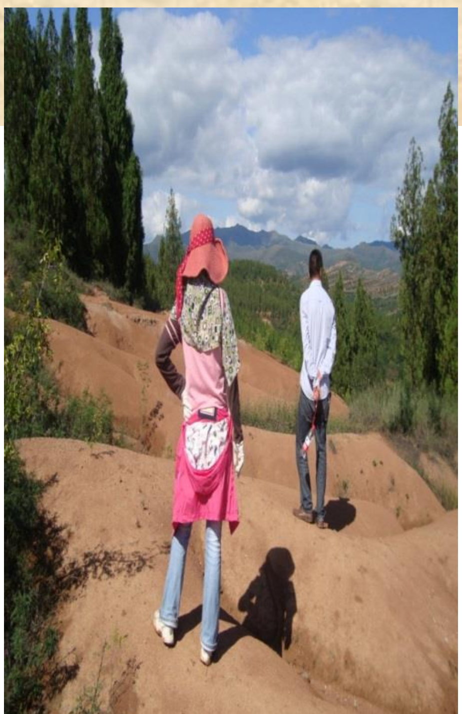
Case study II: Impacts of afforestation on soil organic C and N dynamics

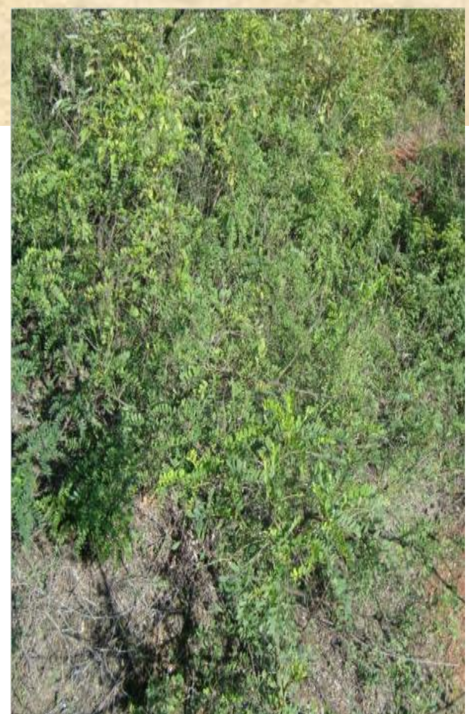


Field work

Afforestation

uncultivated land (U) | **Cropland (C)** | **Shrubland（S）** | **Woodland（W）**

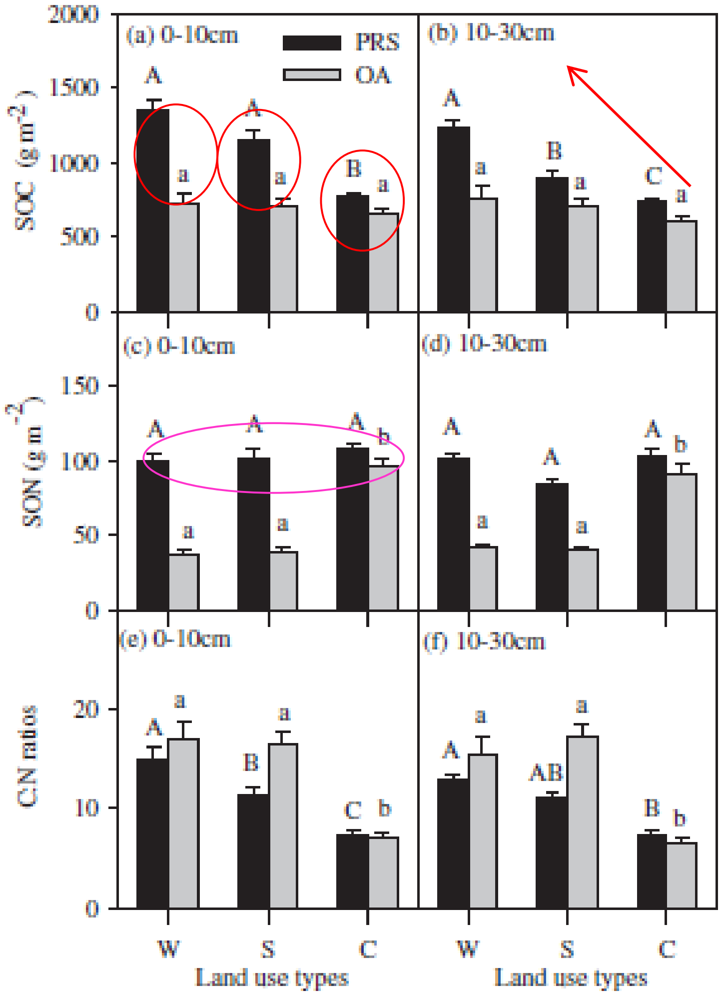




Field work

- ✓ **<u>Plant traits</u>**: Litter biomass, root biomass, litter biomass, C: N ratios, ^{13}C (‰), ^{15}N (‰)
- ✓ **<u>Soil properties</u>**: Moisture, Temperature, Bulk density, pH and so on
- ✓ **<u>Soil carbon and nitrogen and fractions:</u>** Soil labile and recalcitrant C and N pools, aggregates, ^{13}C (‰), ^{15}N (‰)
- ✓ **<u>Soil Microbe</u>**: MBC, MBC, ^{13}C (‰), ^{15}N (‰), PLFAs (F:B ratio), soil microbial respiration

Afforestation increased soil organic C pools but not N pools



Deng *et al.* 2014 *Soil Biol Biochem*

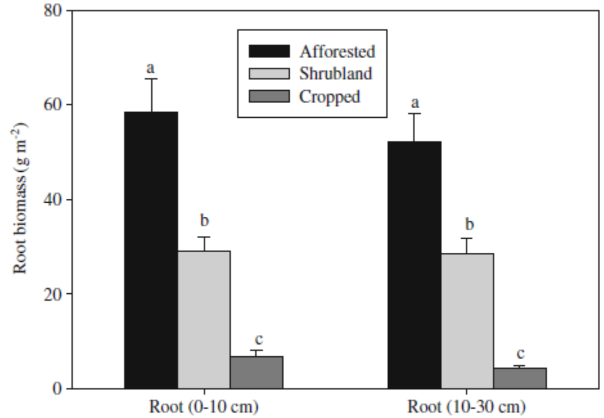


Fig. 2 Root biomass at two depths and leaf litter mass (mean ± SE) under different land use. Letters a, b, c, and d indicate statistical significance at $P<0.05$ among the three land use types

✓ Afforestation increased litter input

Table 2 The $\delta^{13}C$ and $\delta^{15}N$ values of organic soils in plant root-sphere and open area under different land use at two depths

Land use	Depth (cm)	$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)	
		PRS	OA	PRS	OA
Afforested	0–10	−20.65±2.61^{b}	−16.19±3.40^{a}	−0.52±0.16^{b}	2.71±0.79^{a}
	10–30	−19.17±3.23^{b}	−14.87±3.55^{a}	0.46±0.13^{b}	3.03±0.62^{a}
Shrubland	0–10	−18.27±2.84^{b}	−15.93±4.36^{a}	1.18±0.61^{b}	3.07±0.86^{a}
	10–30	−16.51±2.28^{b}	−15.01±2.28^{a}	1.99±0.71^{b}	3.14±0.67^{a}
Cropped	0–10	−20.54±4.37^{b}	−13.63±1.15^{a}	3.02±0.45^{a}	3.15±0.43^{a}
	10–30	−20.17±2.16^{b}	−13.86±0.74^{a}	2.51±0.63^{a}	2.67±0.15^{a}
Source of variation					
Land use		n.s	n.s	***	n.s.
Depth		n.s	n.s	n.s	n.s
Land use × Depth		n.s	n.s	n.s	n.s

✓ Croplands associated with N losses tend to be enriched with δ^{15}N

Table 4 New C input (f_{new}), and decay rate (k, yr^{-1}) of old C of organic soils under different land use at two soil depths

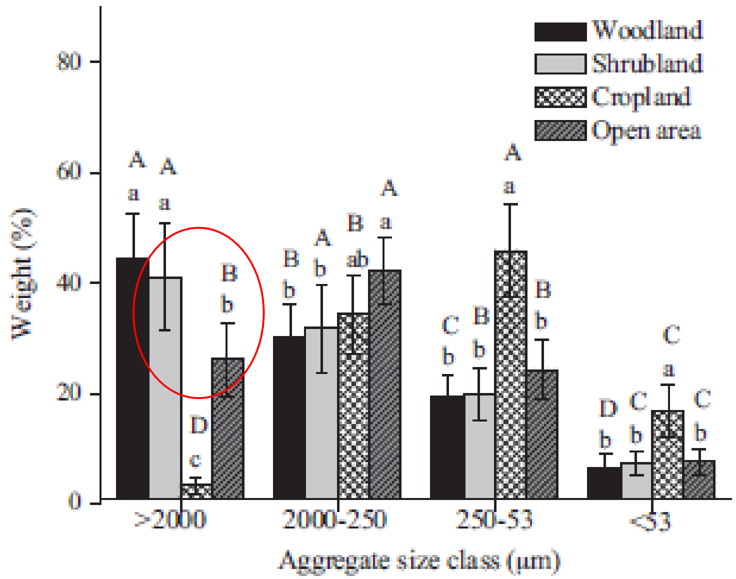
Land use	Depth (cm)	f_{new} (%)	Decay rate (k) of old C
Afforested	0–10	44.4±5.3	0.039±0.004
	10–30	37.8±3.3	0.032±0.003
Shrubland	0–10	22.8±2.9	0.019±0.003
	10–30	13.4±2.1	0.010±0.002
Cropped	0–10	55.6±6.7	0.054±0.007
	10–30	51.8±5.5	0.049±0.005
Source of variation			
Land use		**	**
Depth		n.s	n.s
Land use × Depth		n.s	n.s

Values are mean (n=18) with standard error. Statistically significant differences are given after factorial ANOVA (*n.s.* not significant; *$P<0.05$; **$P<0.01$; ***$P<0.001$)

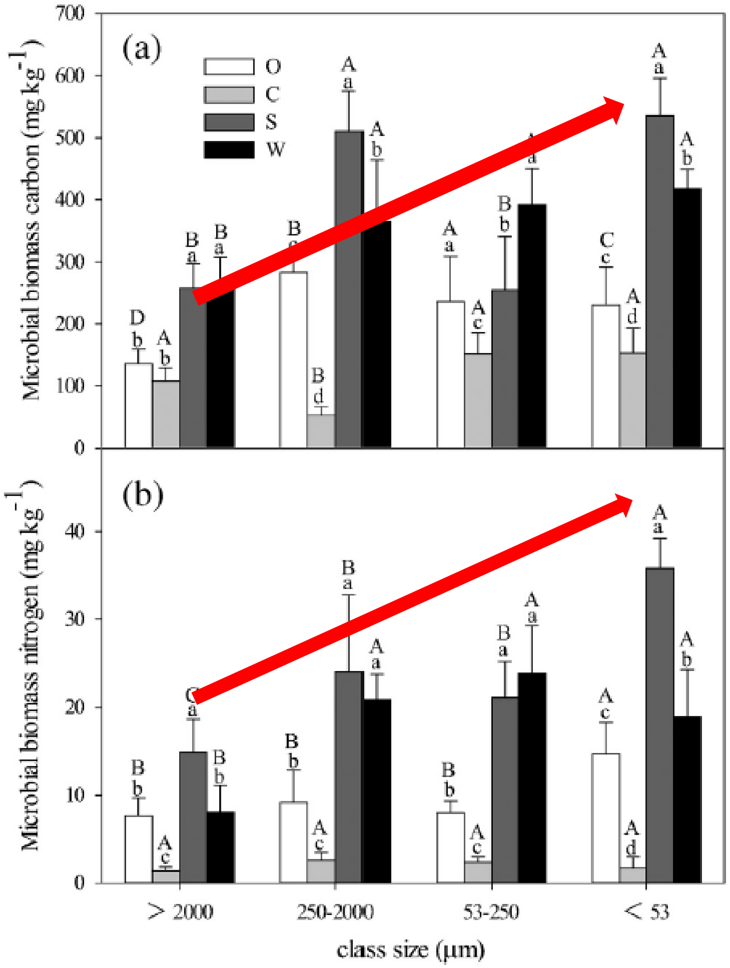
✓ Decay rate was lower in afforested soil than cropland

Cheng *et al.* 2013 Plant Soil

Afforestation impacted soil C, N and microbial biomass in aggregates



Dou *et al.* 2016 2016
Ecol Engineering



Wu *et al.* 2016 *Sci Total Environ*

The δ^{13}C and δ^{15}N values and the ^{13}C and ^{15}N enrichment of soil microbial biomass

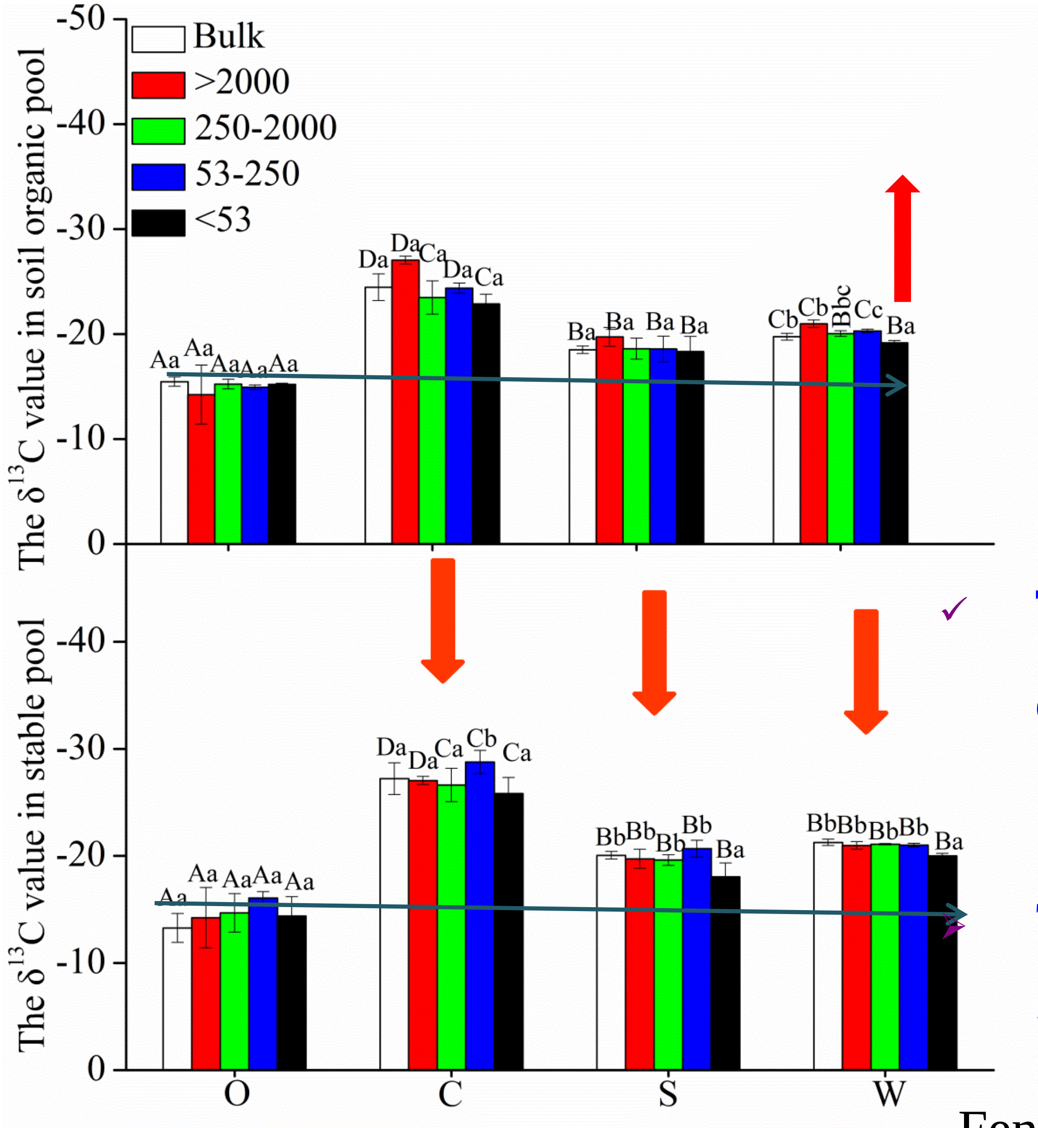
The δ^{13}C and δ^{15}N values and the ^{13}C and ^{15}N enrichment of soil microbial biomass relatively to the resources under different land use types.

Land use	Size class (μm)	$\delta^{13}C_{MB}$	$\Delta^{13}C_{MS}$	$\delta^{15}N_{MB}$	$\Delta^{15}N_{MS}$
Open area	>2000	−16.39 ± 4.42	−0.92 ± 0.16	14.58 ± 2.11	2.79 ± 2.16
	250–2000	−15.89 ± 2.77	−2.75 ± 1.64	14.14 ± 0.78	1.94 ± 0.39
	53–250	−19.59 ± 4.07	−5.22 ± 1.12	11.31 ± 0.87	1.76 ± 0.92
	>53	−16.94 ± 1.33	−2.97 ± 1.53	12.61 ± 1.08	2.49 ± 1.71
Cropland	>2000	−22.10 ± 2.68	−2.47 ± 0.42	12.37 ± 1.89	5.60 ± 0.24
	250–2000	−19.12 ± 1.59	0.72 ± 0.60	14.43 ± 2.75	6.14 ± 2.15
	53–250	−23.43 ± 1.77	3.06 ± 1.91	15.88 ± 2.12	6.75 ± 2.06
	>53	−23.04 ± 5.85	−4.70 ± 1.40	15.10 ± 2.50	5.67 ± 2.06
Shrubland	>2000	−23.61 ± 0.94	−1.43 ± 0.85	9.53 ± 1.62	4.10 ± 1.81
	250–2000	−23.45 ± 4.06	−2.19 ± 0.55	8.88 ± 1.67	4.88 ± 1.26
	53–250	−26.99 ± 3.59	−2.88 ± 1.44	8.89 ± 1.49	3.87 ± 0.95
	>53	−24.86 ± 2.11	−6.06 ± 2.29	9.13 ± 1.42	4.82 ± 1.92
Woodland	>2000	−21.37 ± 5.98	4.94 ± 2.50	5.80 ± 1.51	4.07 ± 0.42
	250–2000	−18.45 ± 3.64	8.15 ± 3.45	5.64 ± 1.07	3.68 ± 1.69
	53–250	−18.97 ± 0.89	7.93 ± 1.59	4.10 ± 1.30	4.93 ± 1.07
	>53	−20.65 ± 3.17	4.94 ± 3.24	7.37 ± 1.88	3.79 ± 1.46

$\Delta^{13}C_{MS}$, $\Delta^{15}N_{MS}$ means ^{13}C and ^{15}N enrichment of microbial biomass compared with these of organic soil.

Wu *et al*. 2016 *Sci Total Environ* 568:52-56

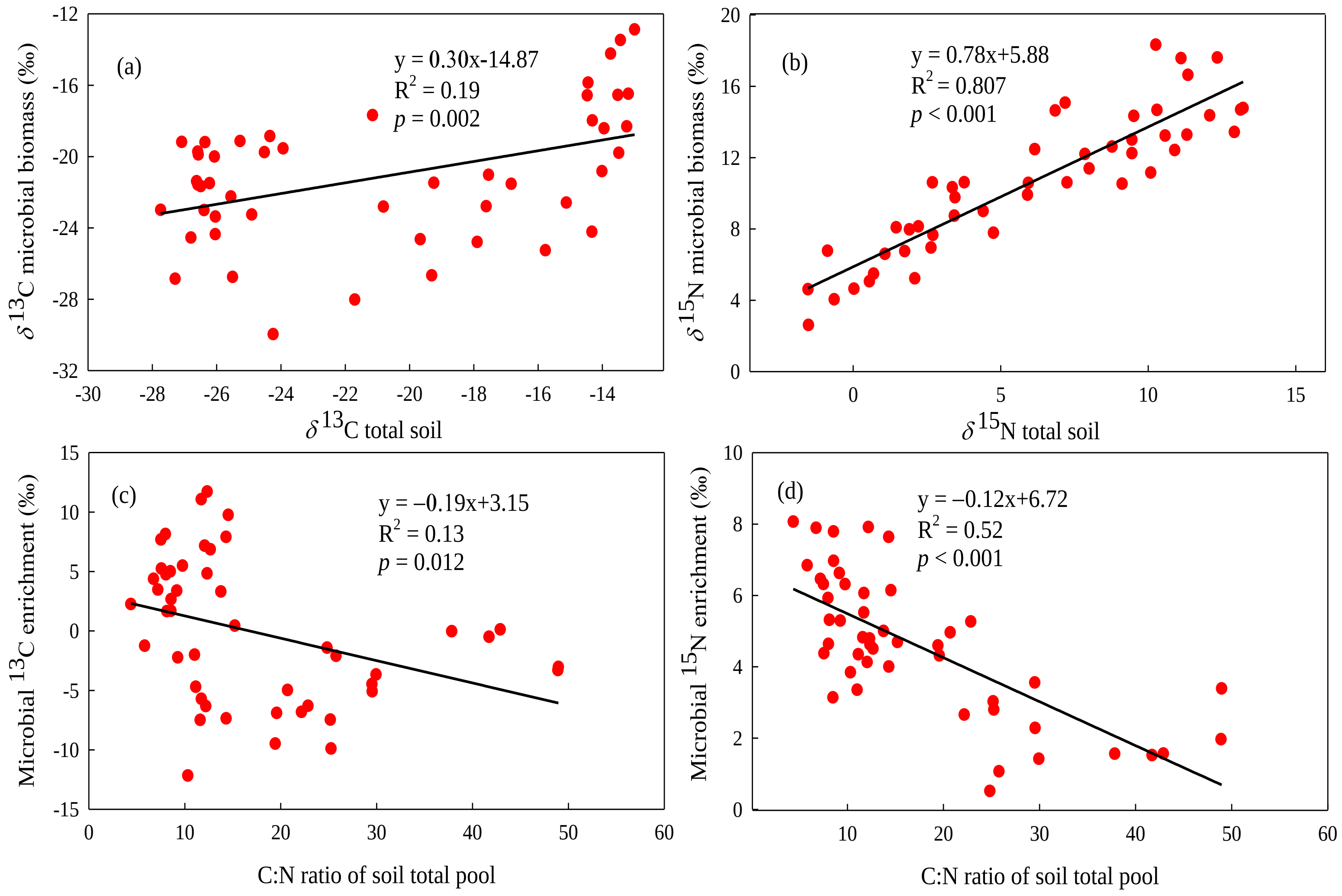
The δ^{13}C in aggregates in response to land use change



- ✓ The δ13C values of soil organic pool were more negative across aggregate sizes
- ✓ The δ13C values in stable organic pool were more negative
- The significant enriched δ13C in < 53 μm particles in woodland

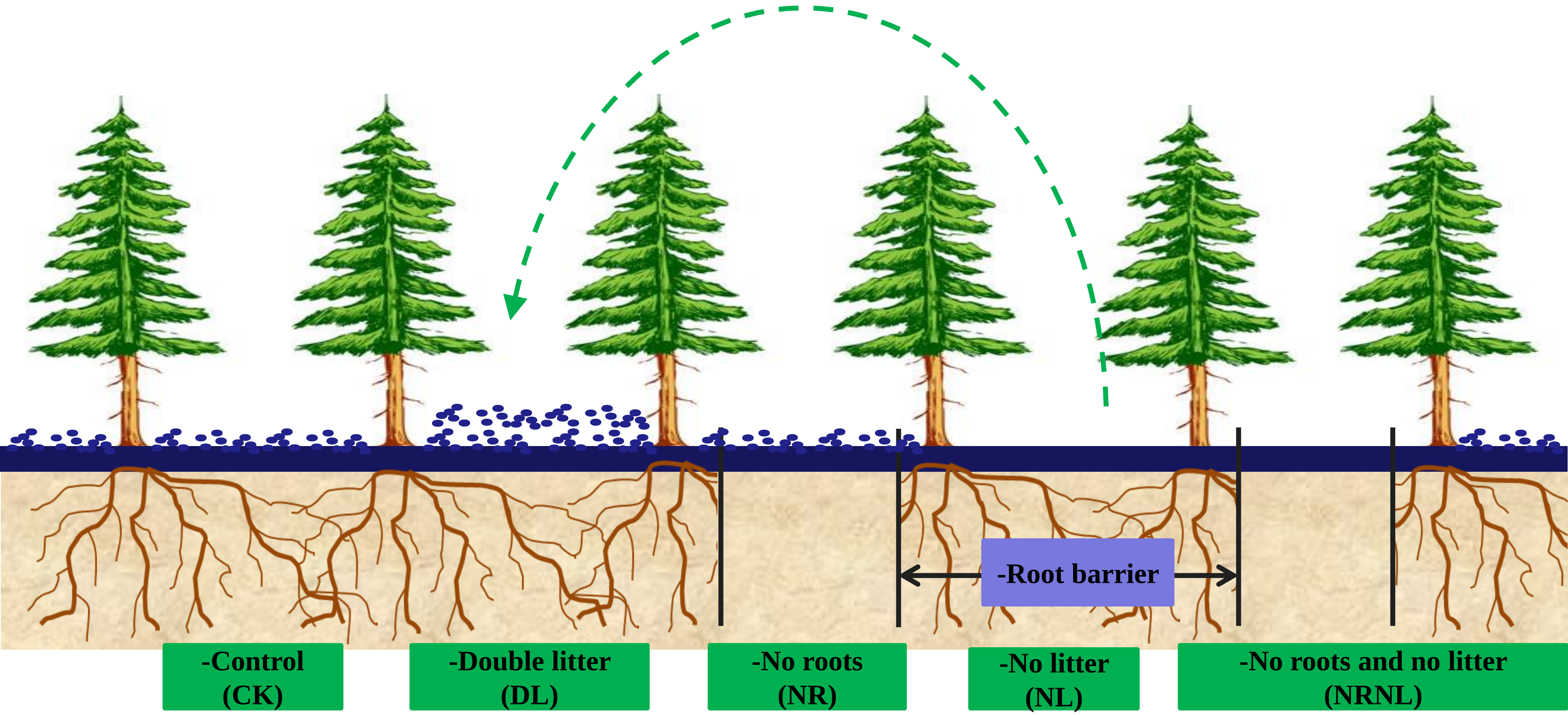
Feng *et al*. 2017 SBB, under review

Controls on the δ^{13}C, δ^{15}N of soil microbial biomass



Wu *et al.* 2016 *Sci Total Environ*

Case study III: Effects of litter input manipulation on soil respiration in forest ecosystem



DIRT (The Detritus Input and Removal Treatment)

（Nadelhoffer *et al*., 2004）

No Root

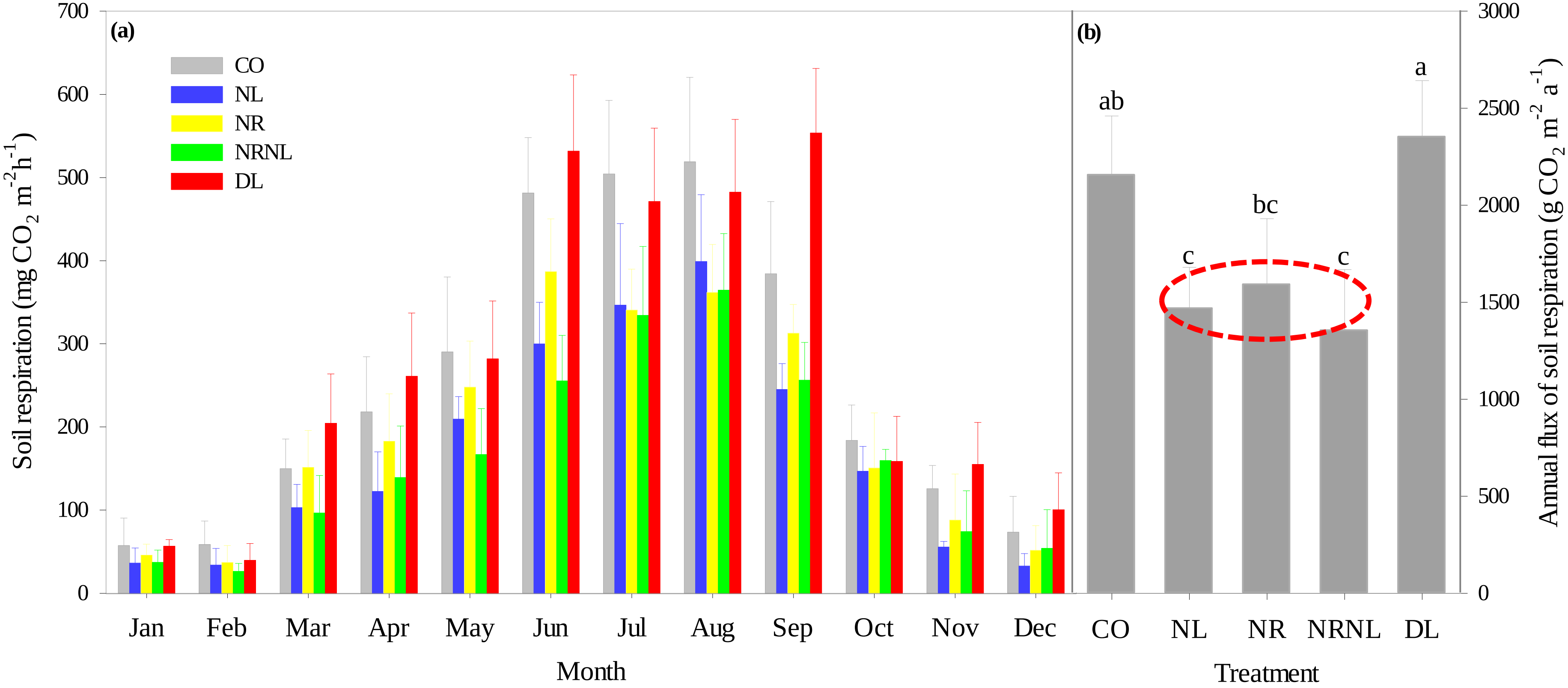
Control

No Litter

No Root and No Litter

Double Litter

Results (Soil respiration)

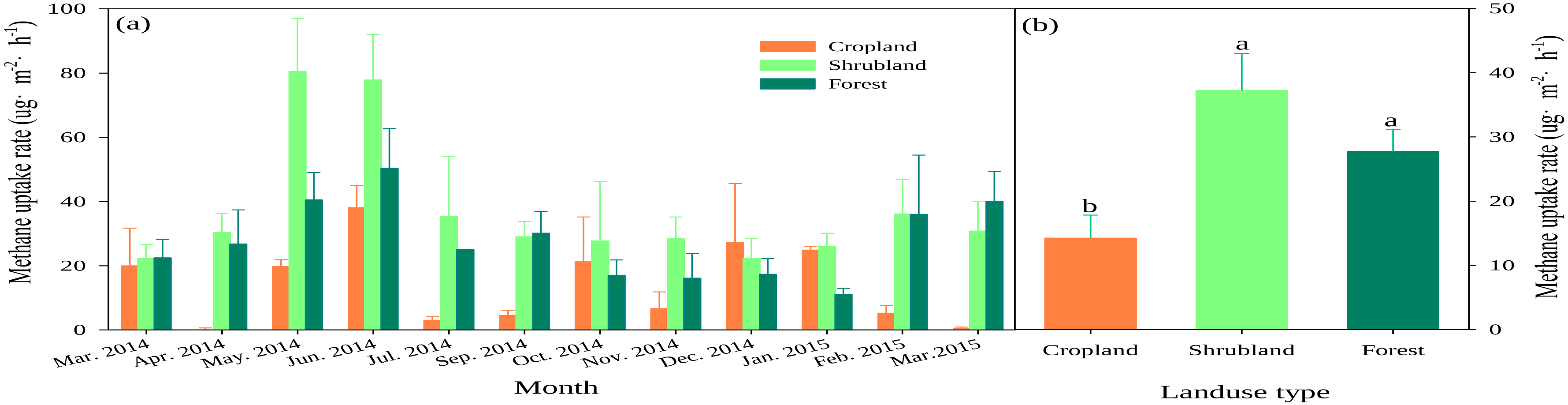


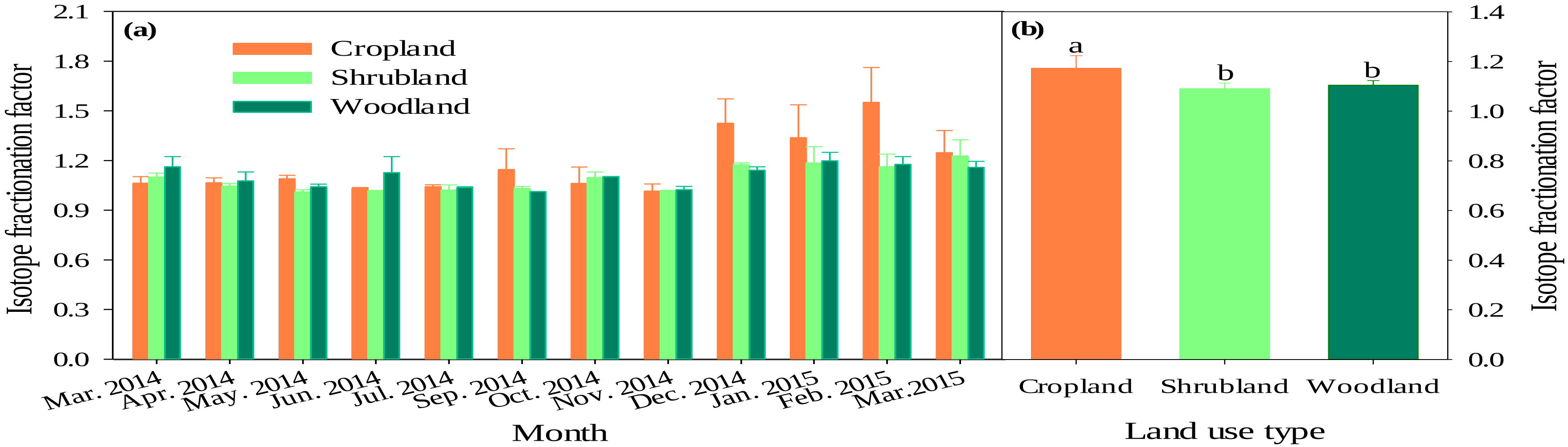
✓ **Litter removal and root exclusion significant decrease soil respiration**

✓ **However, litter addition didn't have significant influence on soil respiration**

Wu *et al.* 2017 *Appl Soil Ecol*

Afforestation enhanced soil CH_4 uptake rate





The isotope fractionation factor (α_{soil}) was lower in woodland and shrubland, compared to cropland

Wu *et al.* 2017 SBB, under review

Summary

- **Globally, SOC decomposition rates varied with temperature and precipitation;** Global warming may accelerate SOC decomposition
- **Afforestation increased soil organic C** increased litter input, lower decay rate
- **Soil respiration was more susceptible to litter removal than litter addition, partly because substrate availability and microbial community structure were more influential in litter removal or root exclusion treatment compared with litter addition**
- **Afforestation enhanced soil CH_4 uptake rate, positively related to microbial biomass carbon (MBC) and labile C, negatively related to inorganic nitrogen (N) concentration; the isotope fractionation factor was negatively related to soil temperature**

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Thanks