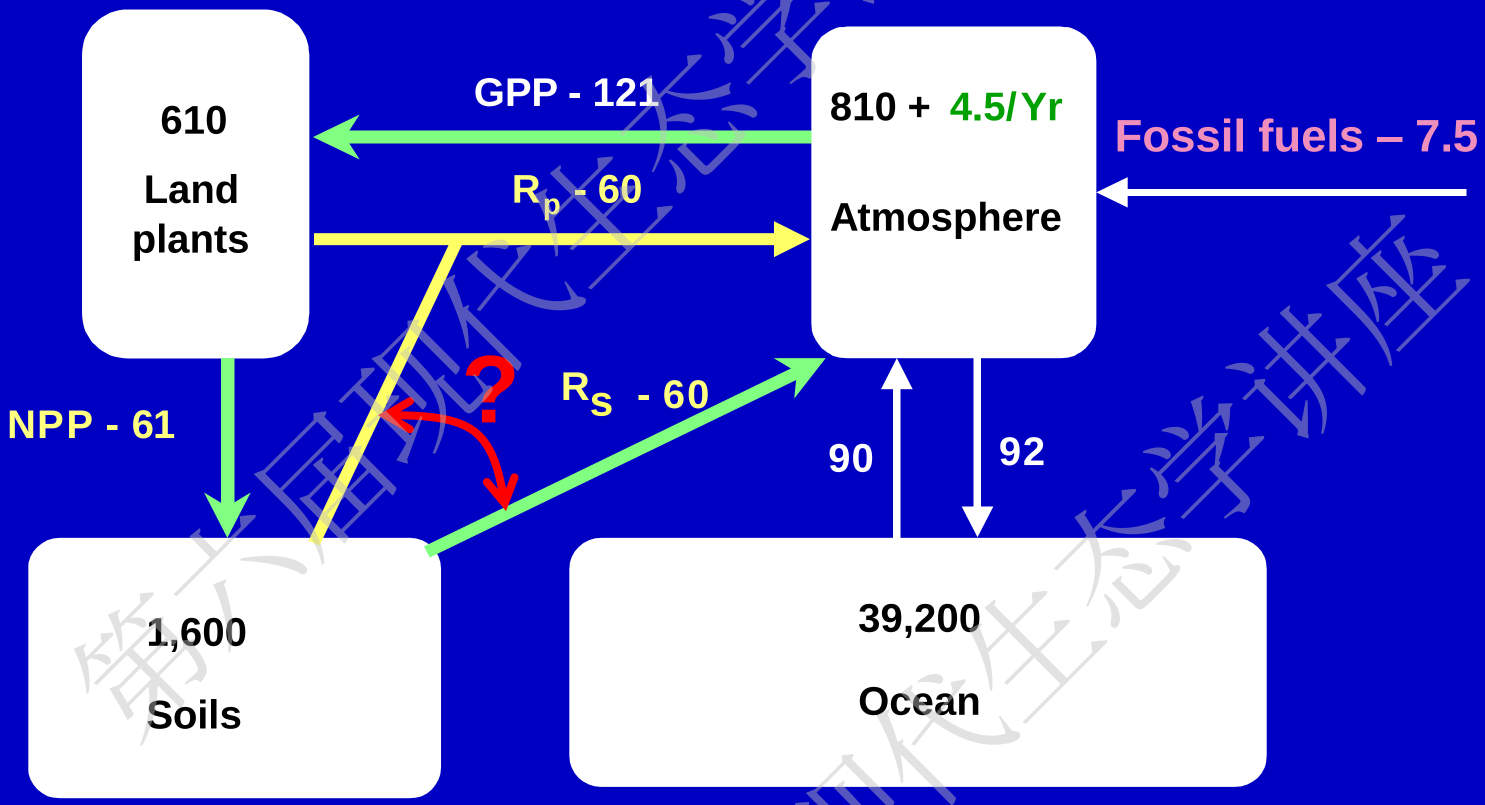
土壤碳库对温度变化的敏感性

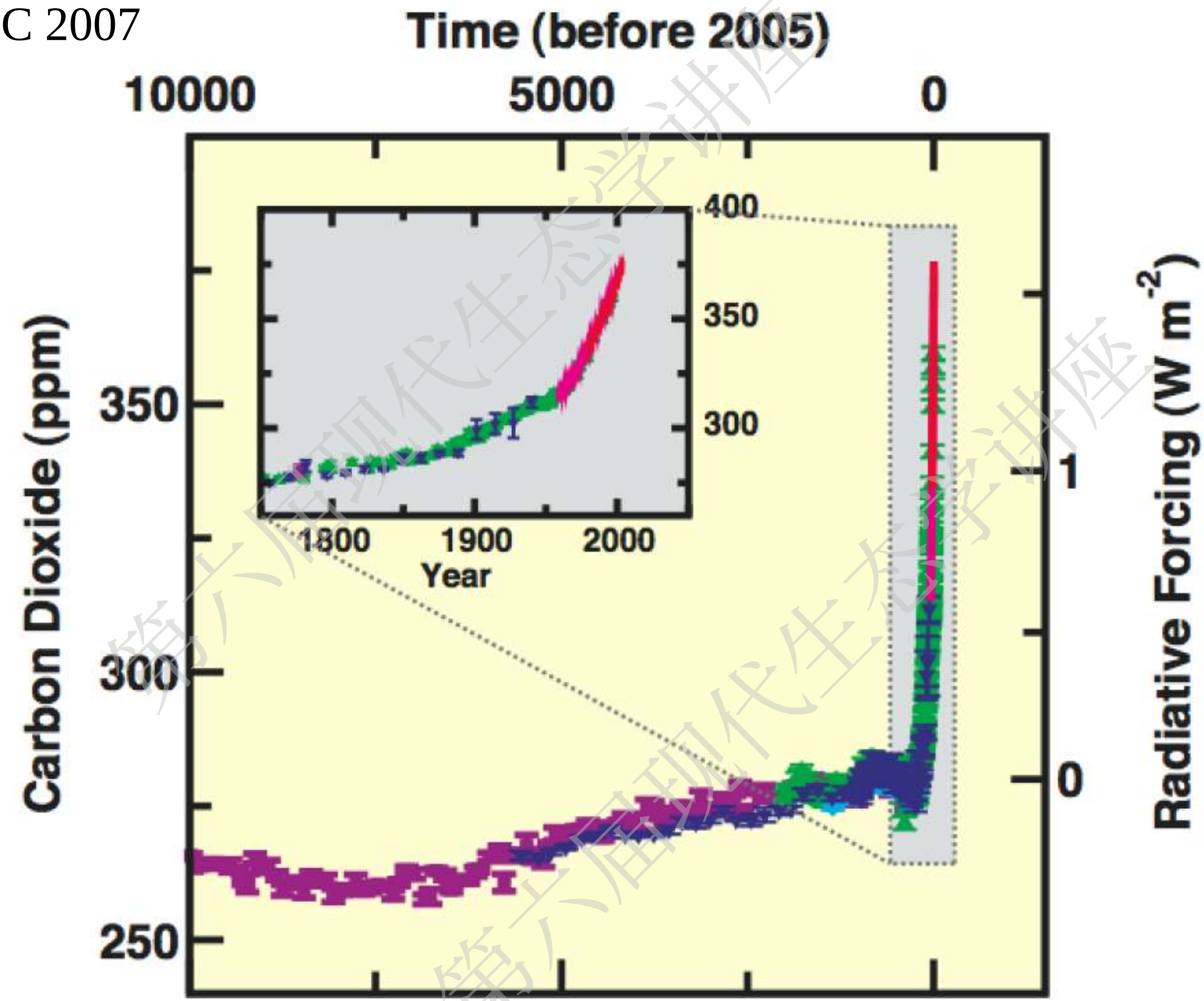
程维信

中科院沈阳应用生态研究所

University of California -Santa Cruz

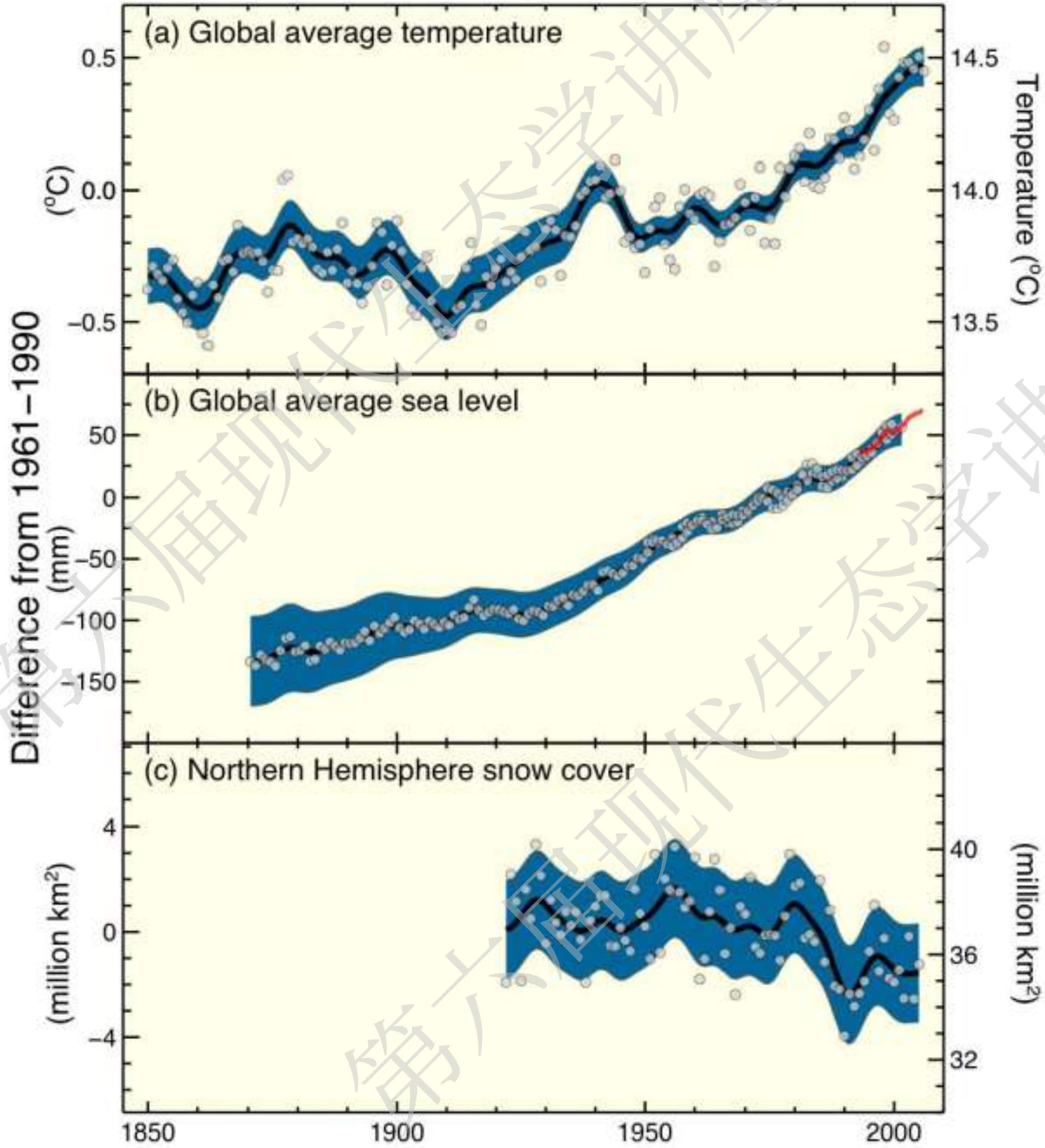

610
Land
plants
GPP - 121
810 + 4.5/Yr
Atmosphere
Fossil fuels – 7.5
Rp - 60
NPP - 61
?
Rs - 60
90
92
1,600
Soils
39,200
Ocean

IPCC 2007

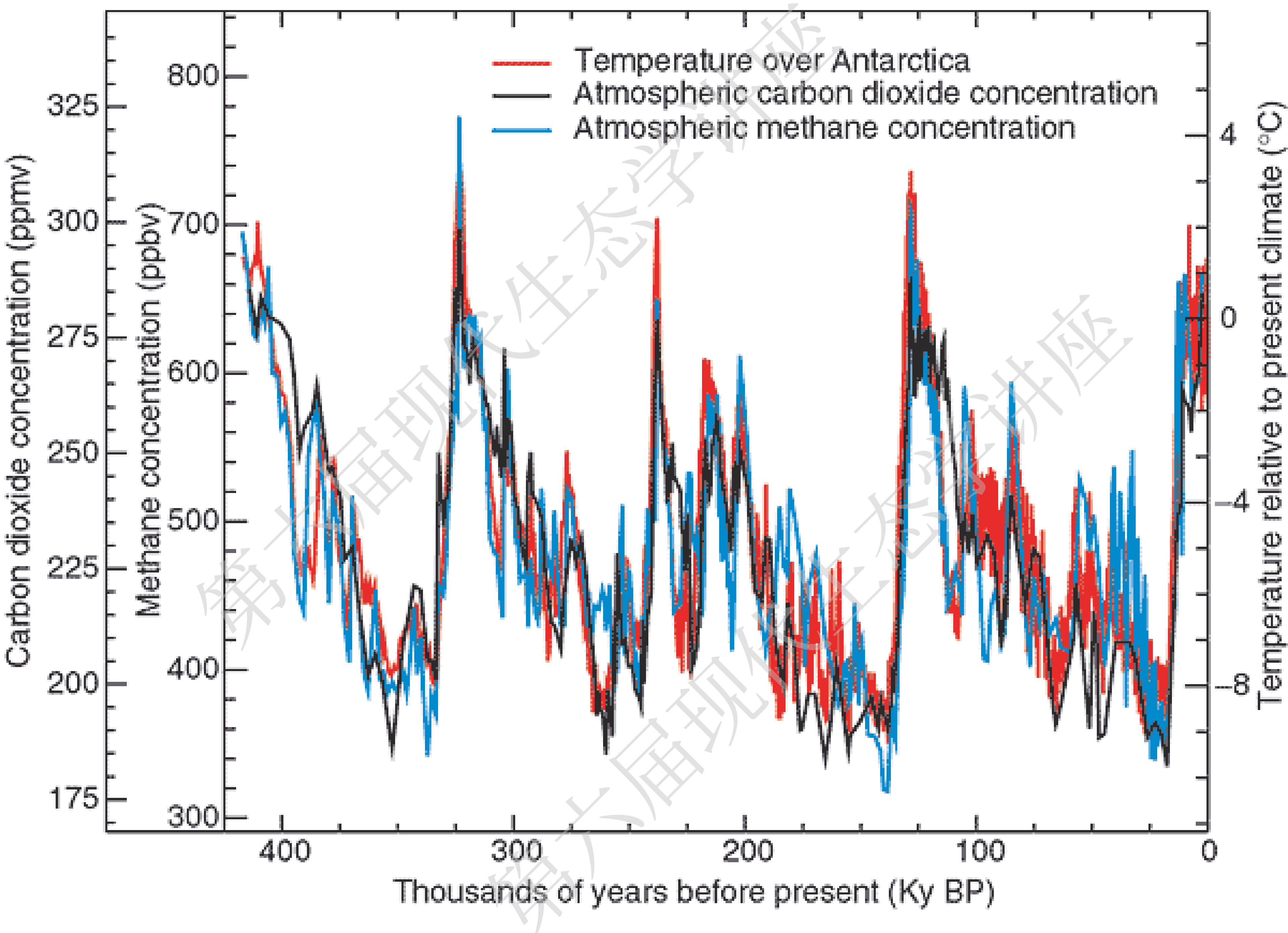


Time (before 2005)
10000
5000
0
Carbon Dioxide (ppm)
350
300
250
Radiative Forcing (W m^{-2})
1
0
400
350
300
1800
1900
2000
Year

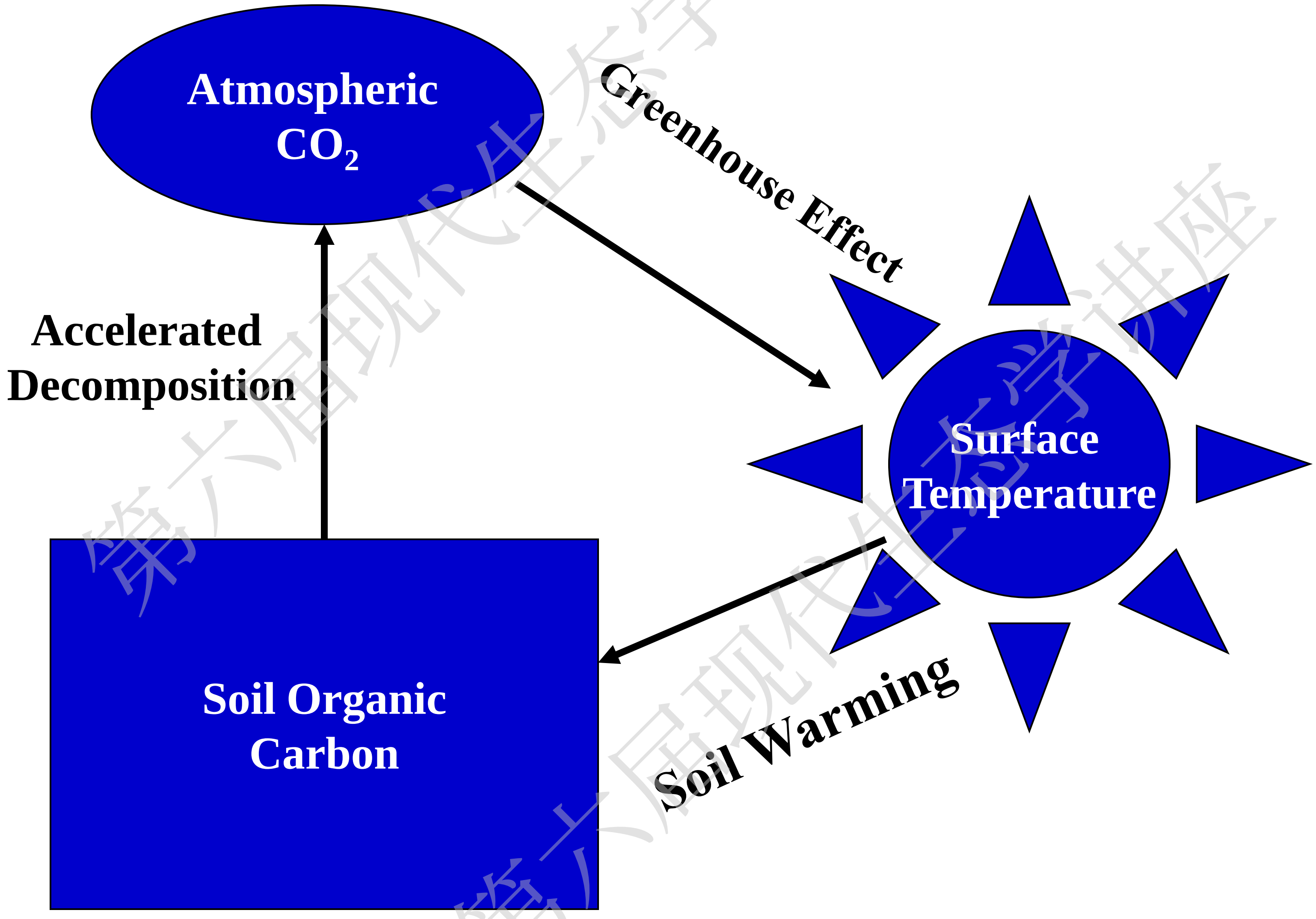
Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover



Baseline=1961-1990;
dots are yearly data,
lines are decadal averages;
shade=uncertainty


Temperature over Antarctica
Atmospheric carbon dioxide concentration
Atmospheric methane concentration
Carbon dioxide concentration (ppmv)
325
300
275
250
225
200
175
Methane concentration (ppbv)
800
700
600
500
400
300
Temperature relative to present climate (°C)
4
0
−4
−8
400
300
200
100
0
Thousands of years before present (Ky BP)
第六届现代生态学讲座

Temperature sensitivity of SOM decomposition and the positive feedback hypothesis



How will soil organic C pool respond to global warming?

1. General temperature sensitivity of SOM decomposition

2. Substrate availability vs. T-sensitivity

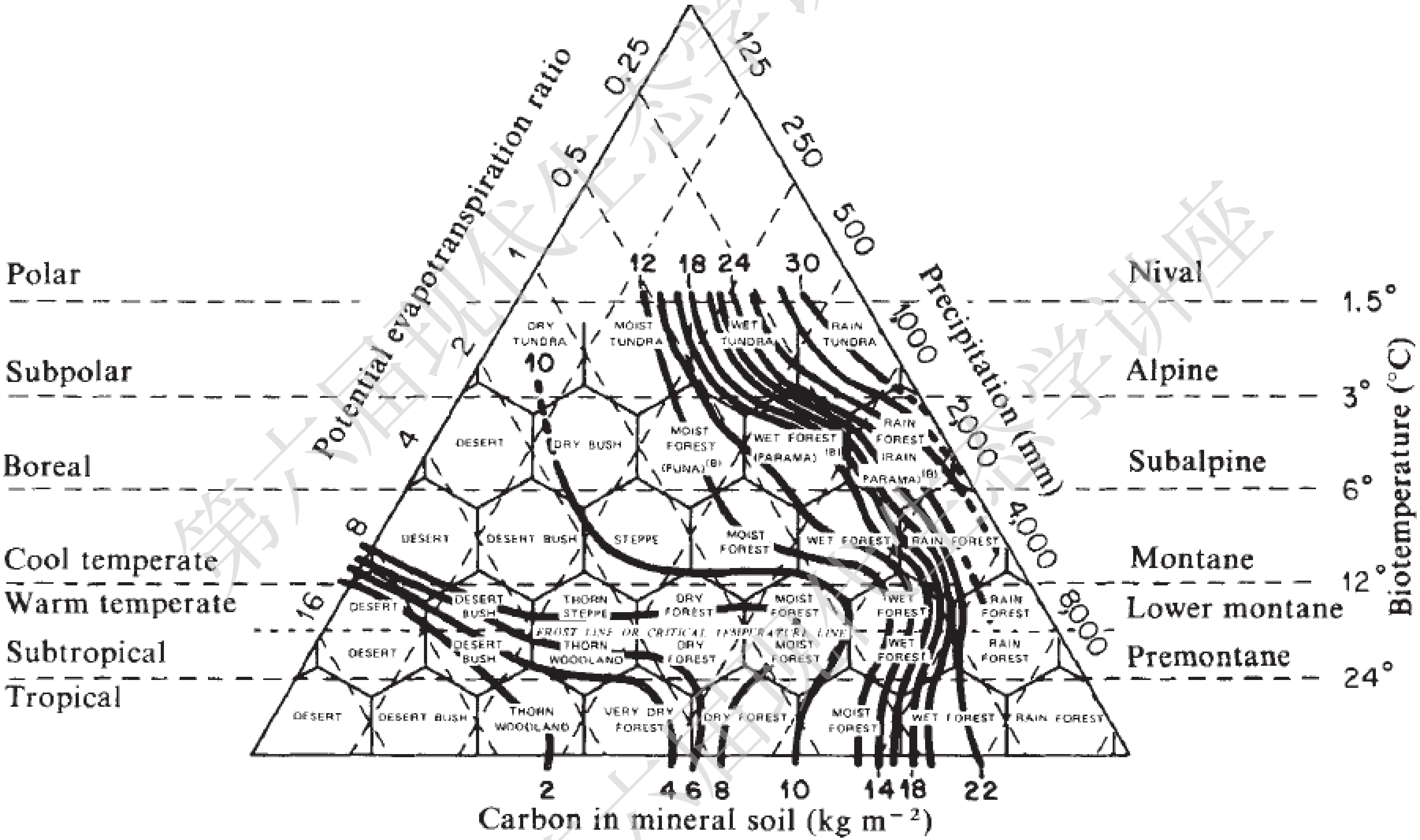
3. T-sensitivity of labile vs. recalcitrant SOM decomposition

4. Rhizosphere interactions vs. T-sensitivity

第六届现代生态学讲座

Soil carbon pools and world life zones

Wilfred M. Post*, William R. Emanuel*,
Paul J. Zinke† & Alan G. Stangenberger†

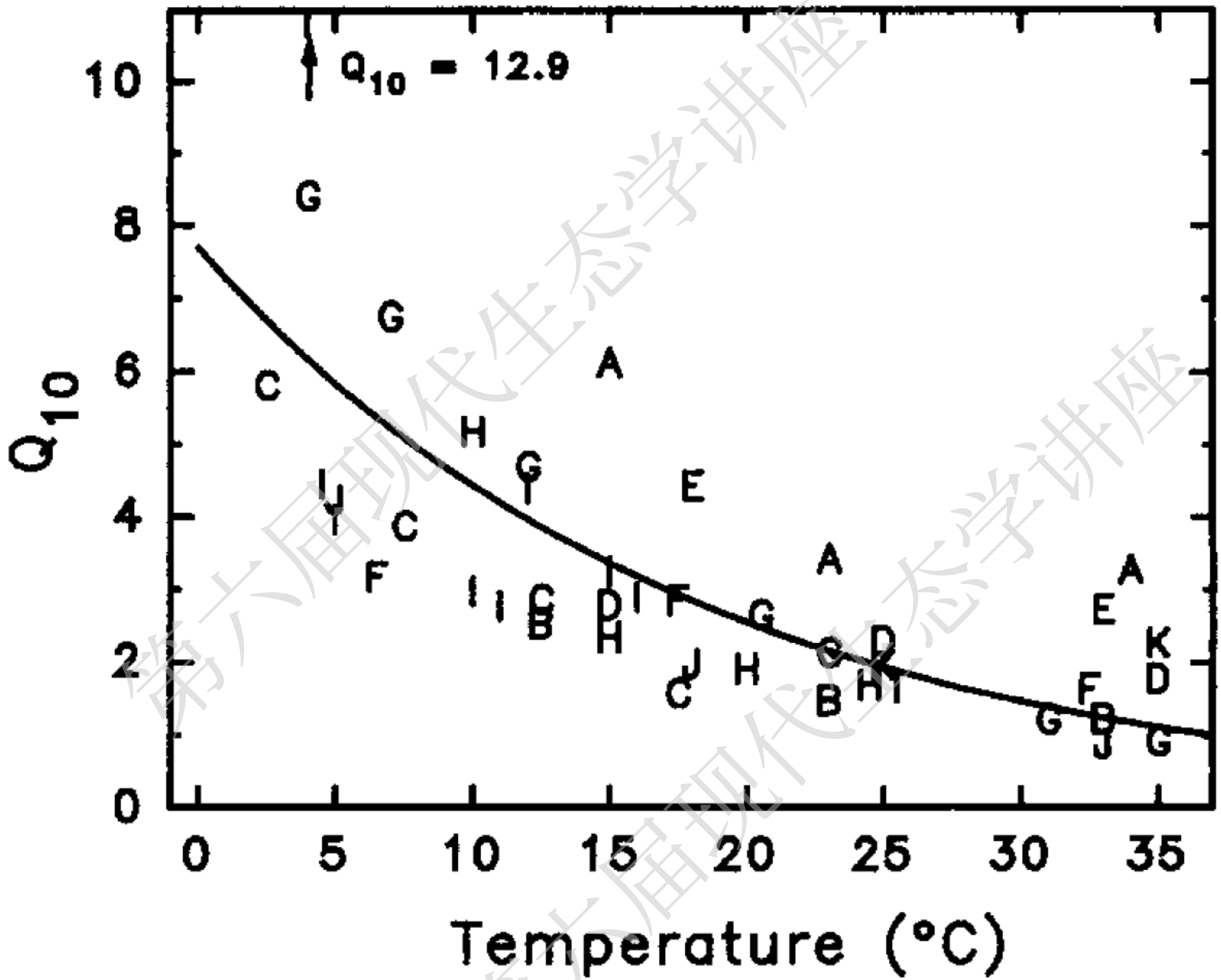


Nature Vol. 298 July 8 1982, page:156-159

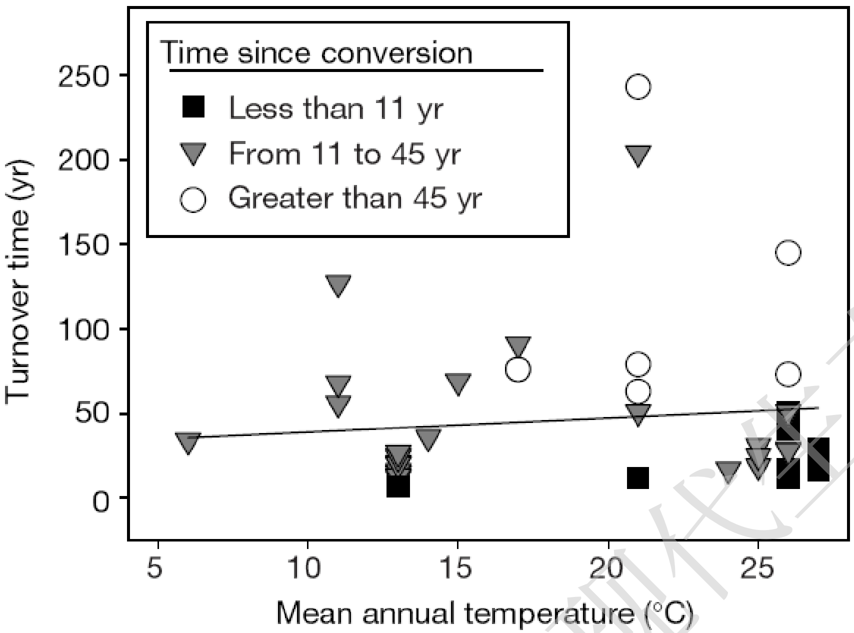
0-1 m depth
Excluding litter layer

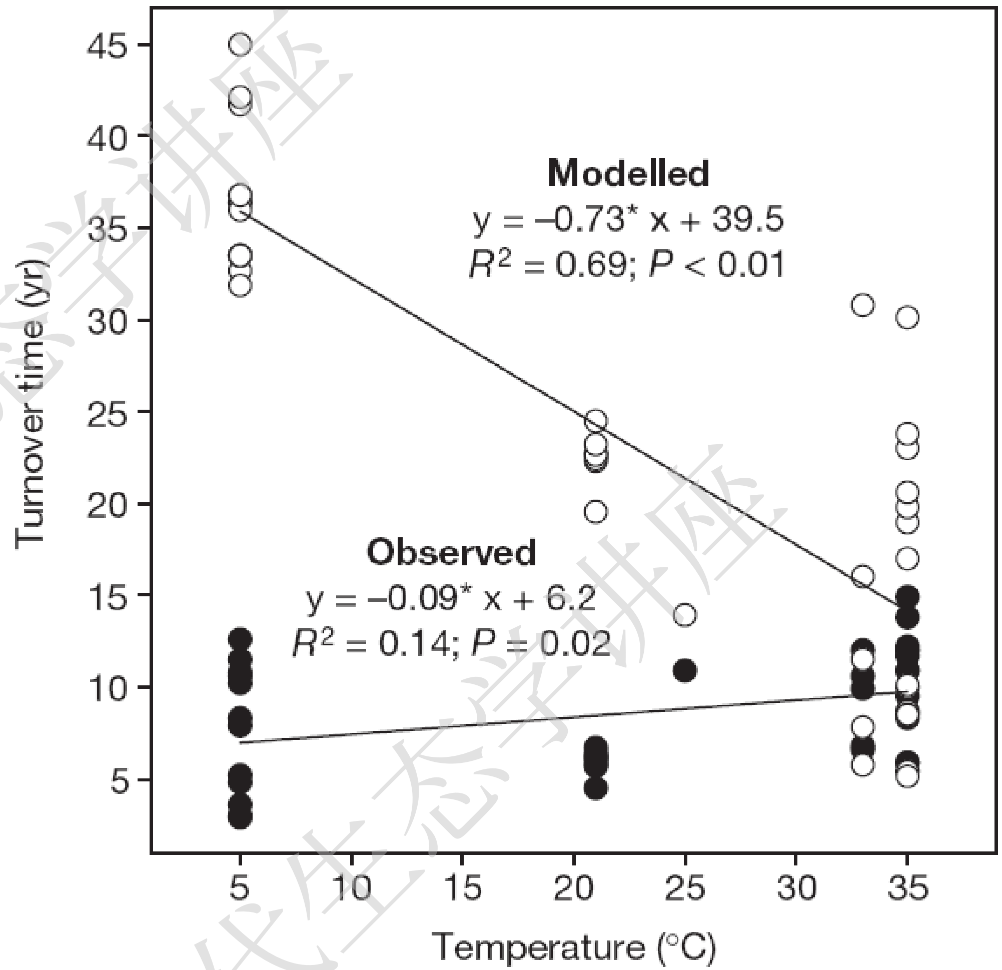
对温度敏感性的研究始于酶动力学. **在最佳温度区间**，在饱和底物浓度条件下，温度每增加10 ℃，多数酶触反应速度增加约一倍。所以 $Q_{10} \approx 2$：

$$Q_{10} = R_{(t+10)} / R_t \approx 2$$



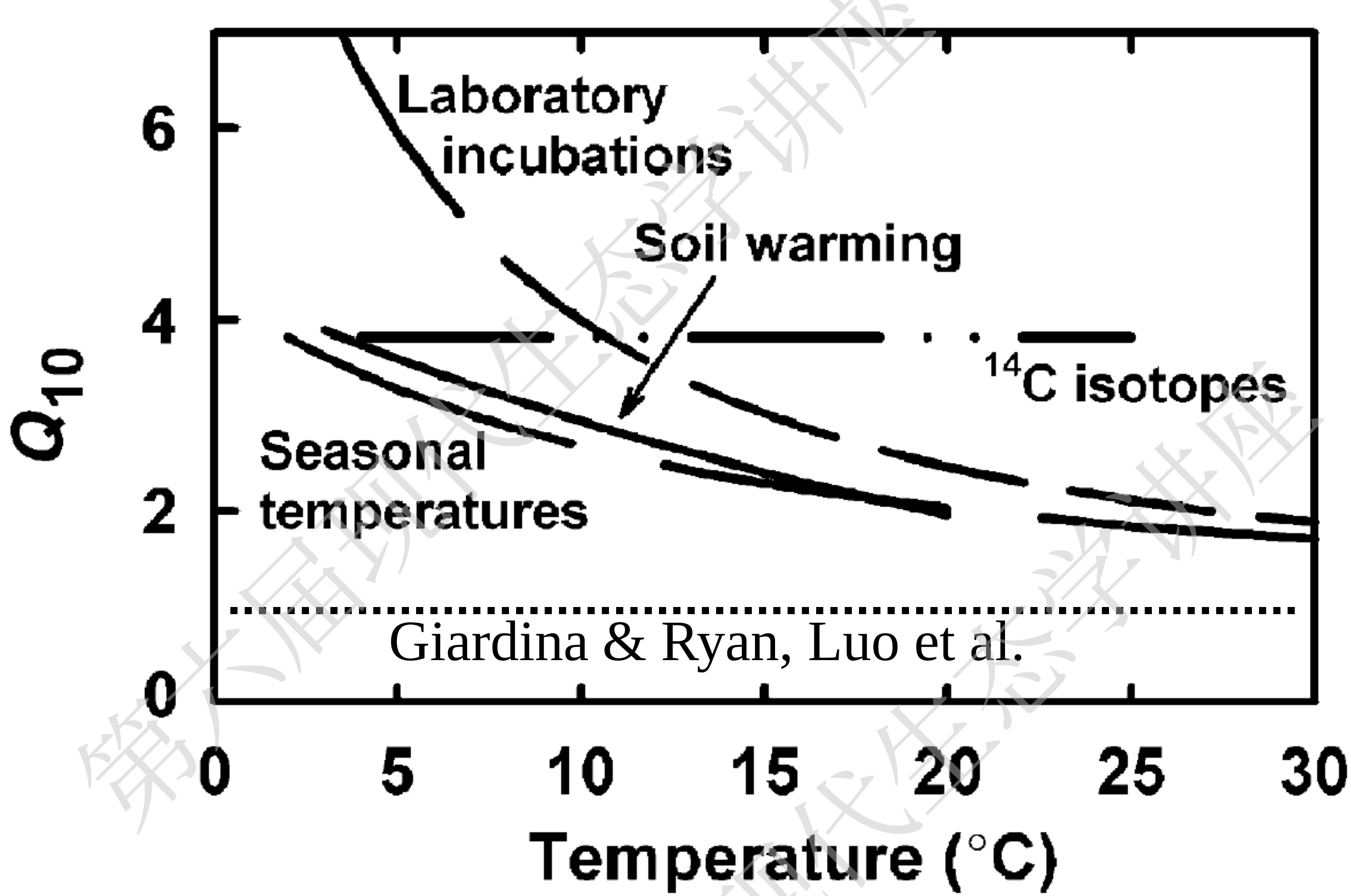
Kirschbaum 1995. SBB





Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature

Christian P. Giardina* & Michael G. Ryan†



Miko Kirschbaum 2004 GCB 10:1870-77

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Michaelis–Menten (MM) kinetics:

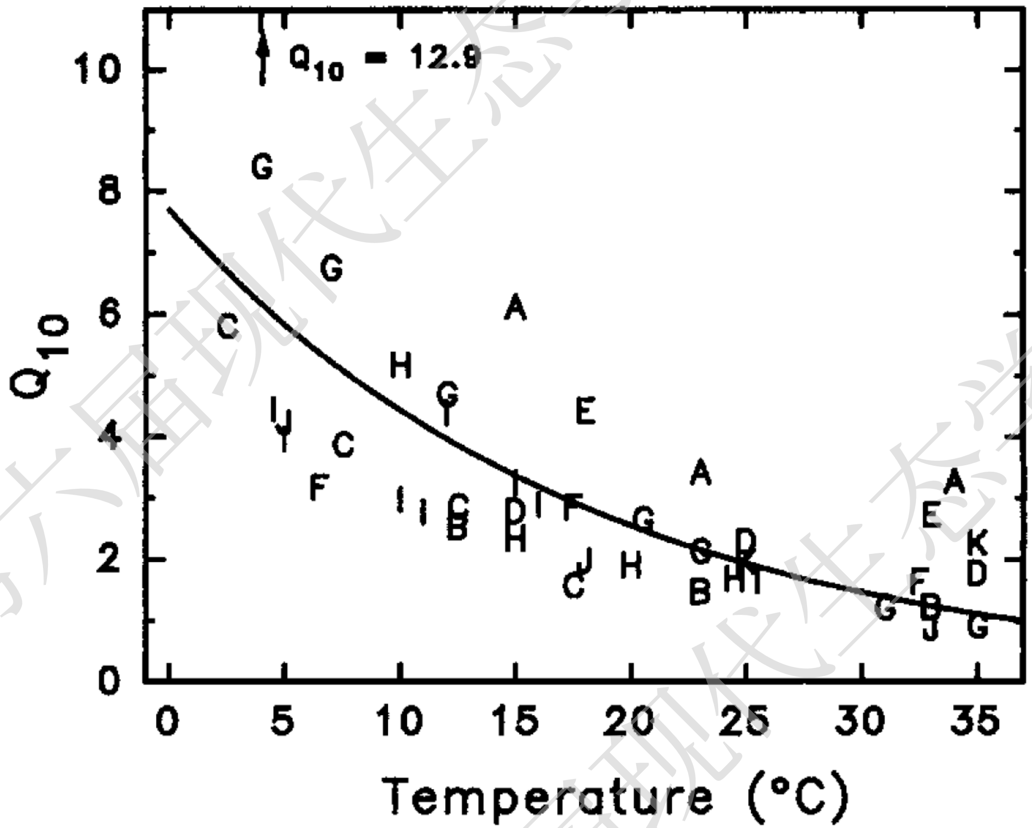
$$R = \frac{V_{\mathrm{max}} \times C}{K_{\mathrm{m}} + C}$$

Theoretically, both $\boldsymbol{V_{max}}$ and $\boldsymbol{K_m}$ are temperature-dependent, but can cancel each other out. $\boldsymbol{K_m}$ is only effective when $\boldsymbol{C}$ is low.

We tested this using glucose saturation.

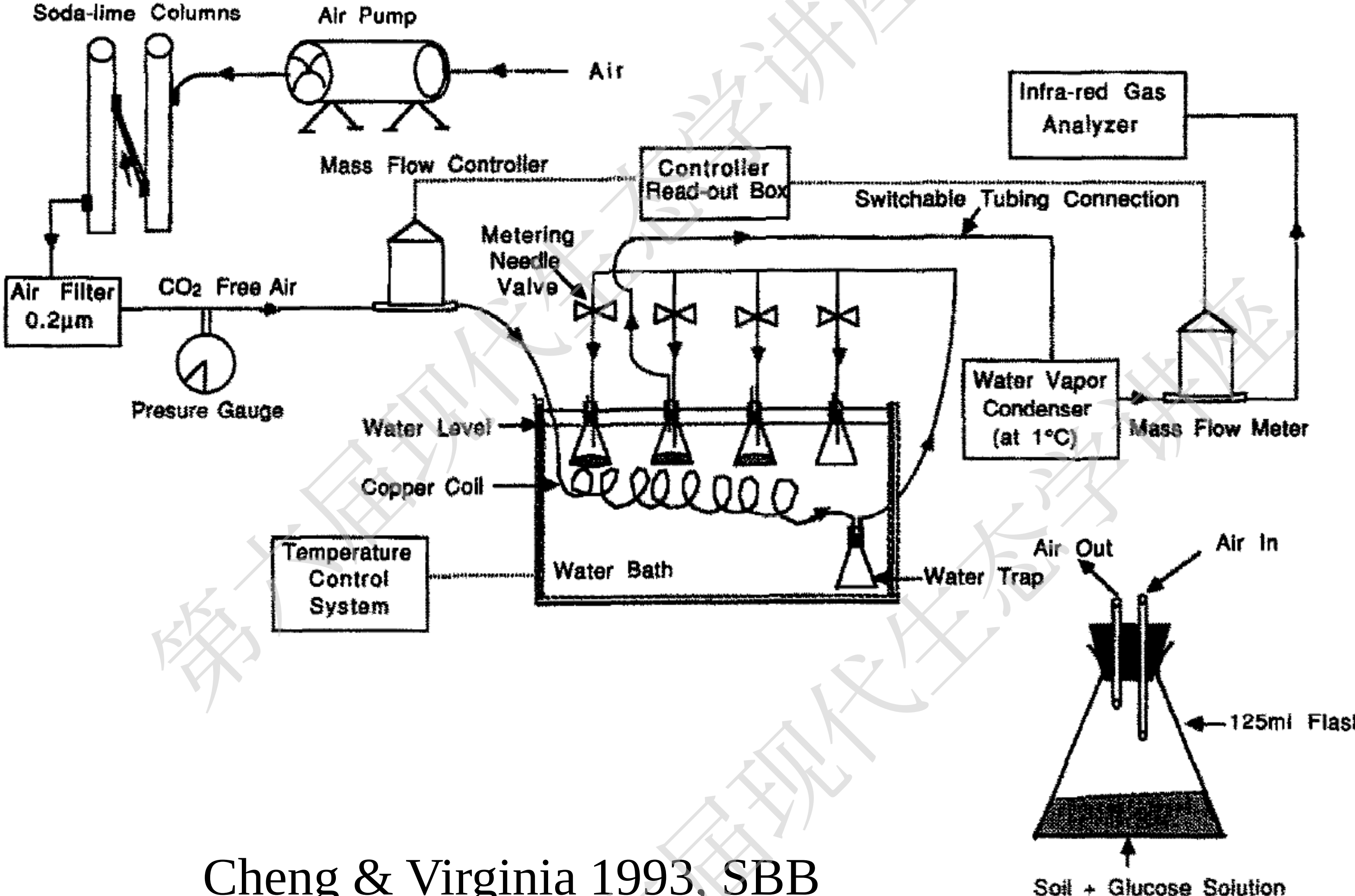
第六届现代生态学讲座

Hypothesis: As incubation temperature increases, substrate availability decreases, the canceling effect of K_m increases, and the apparent Q_{10} value decreases.

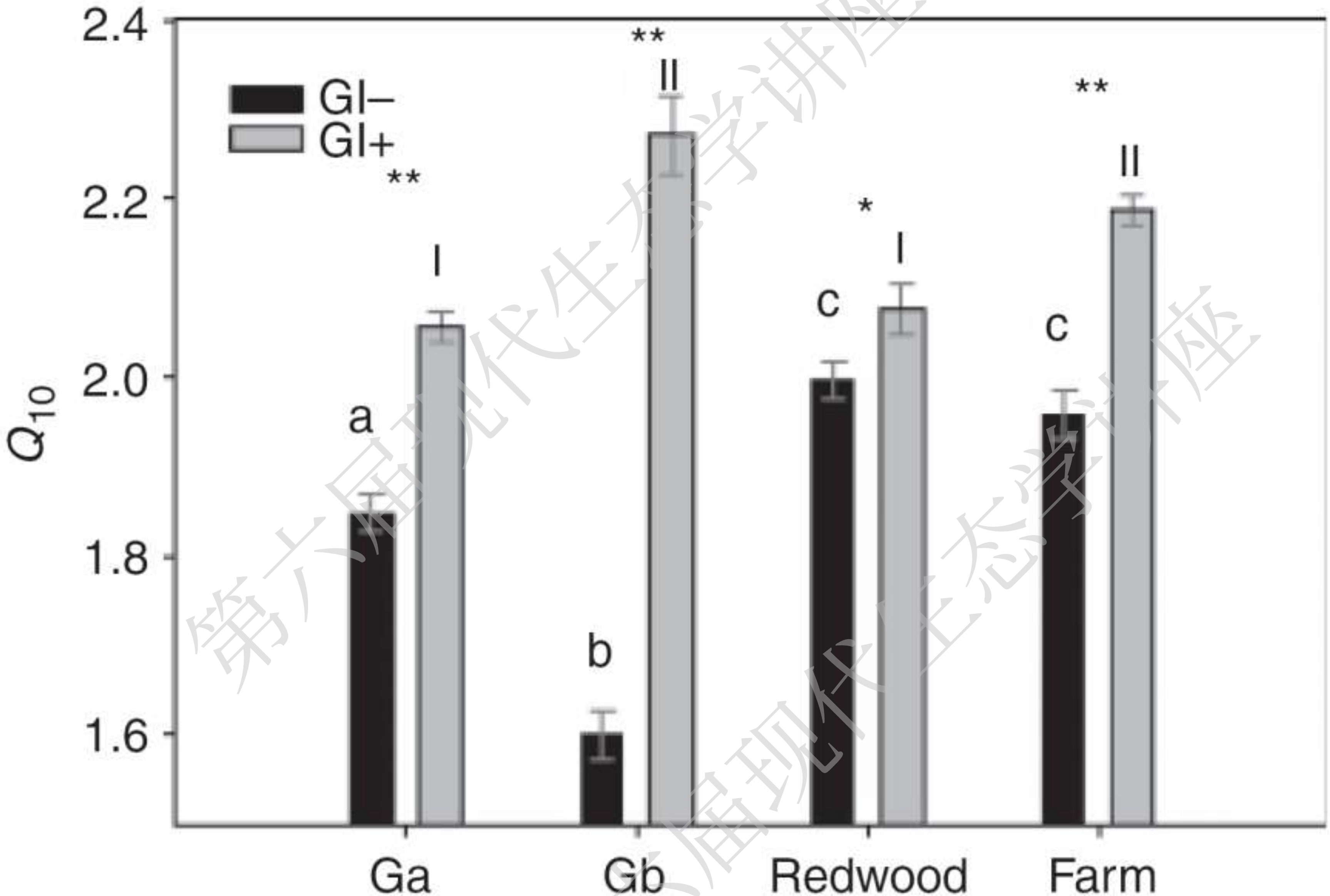


Decreasing [C_a]

Increasing K_m effect



Cheng & Virginia 1993, SBB



Gershenson et al. 2009 GCB

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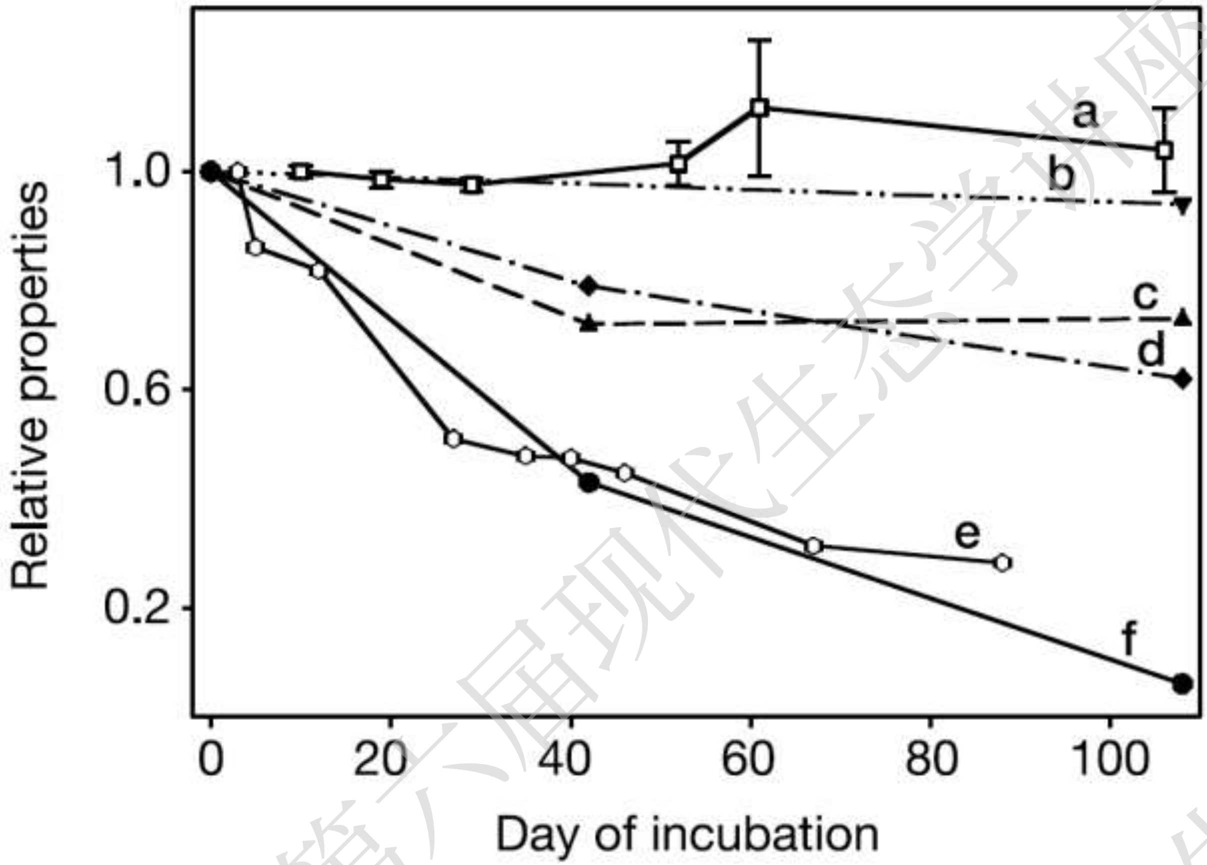
第六届现代生态学讲座

Based on theoretical analysis, Bosatta & Agren 1999 (SBB) concluded that the decomposition of lower quality SOM should have higher temperature sensitivity than higher quality SOM. This conclusion is consistent with Arrhenius (1889) equation----lower quality substrates require higher activation energy.

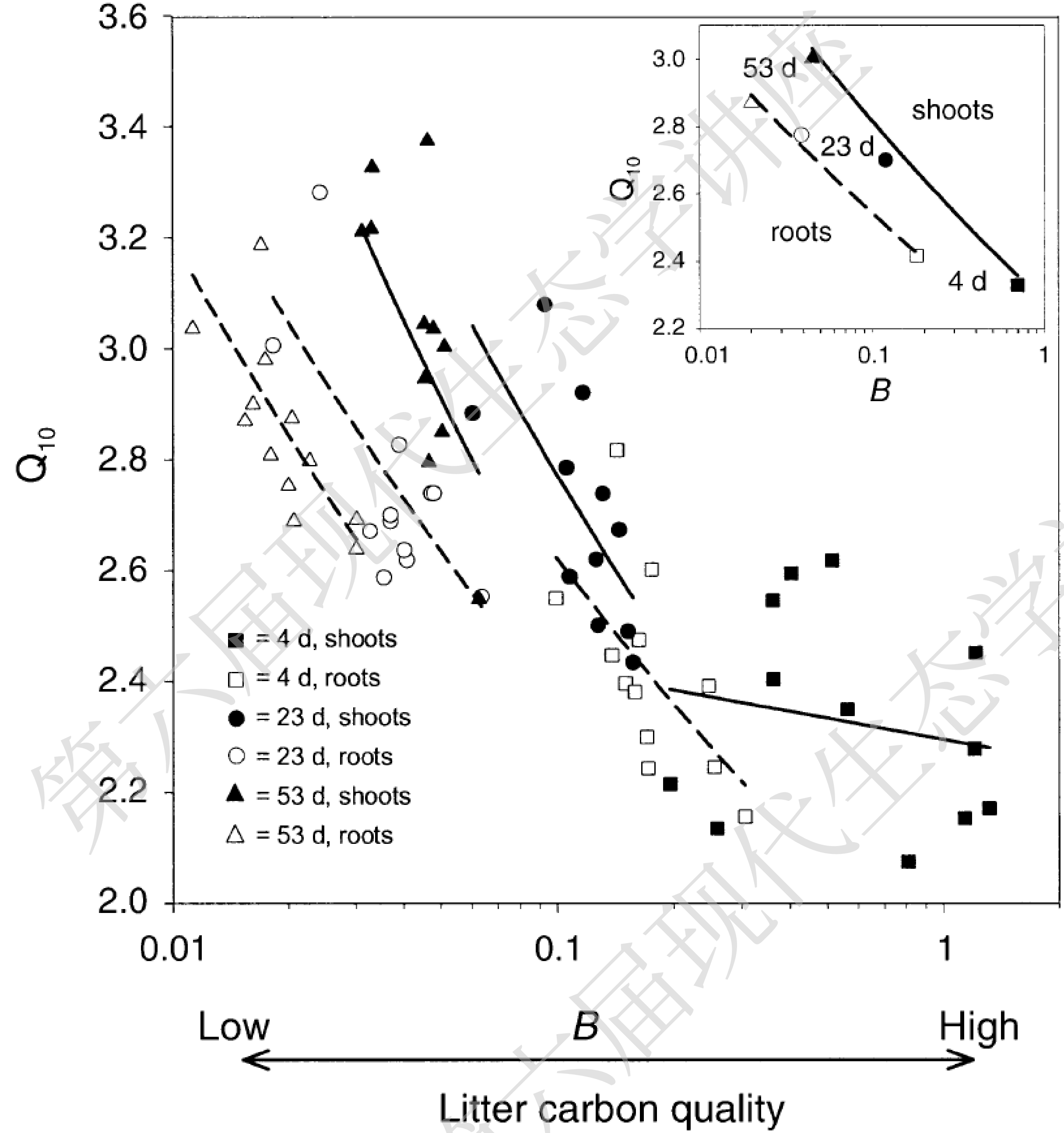


Similar response of labile and resistant soil organic matter pools to changes in temperature

Changming Fang[1], Pete Smith[1], John B. Moncrieff[2] & Jo U. Smith[1]

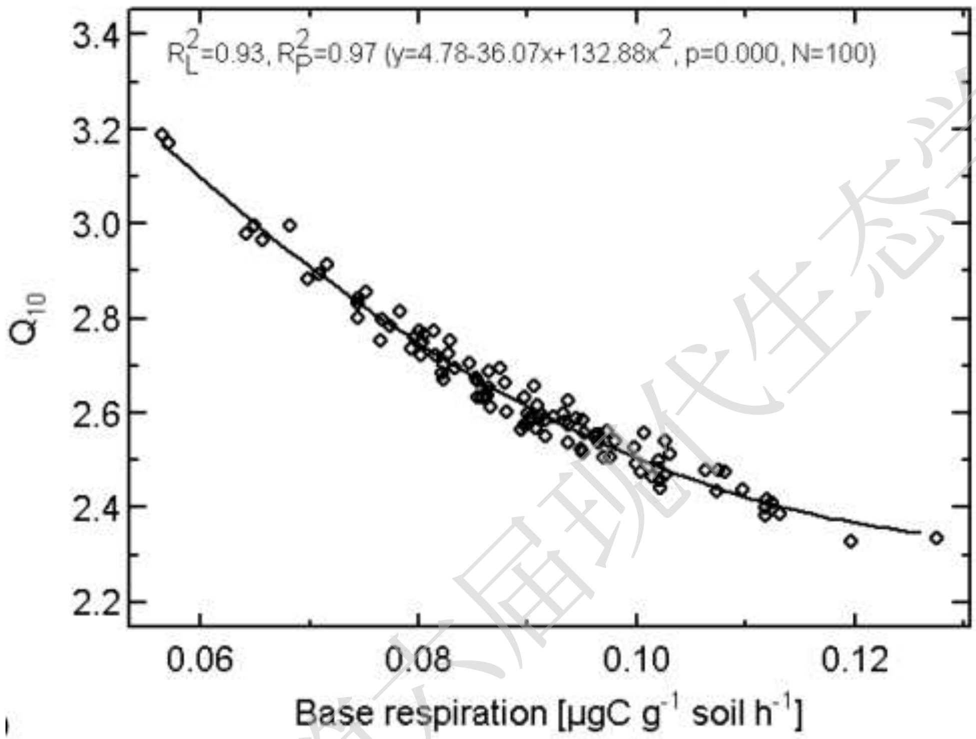
[1]*School of Biological Sciences, University of Aberdeen, Aberdeen AB24 3UU, UK*
[2]*Ecology and Resource Management, School of GeoSciences, The University of Edinburgh, Edinburgh EH9 3JU, UK*

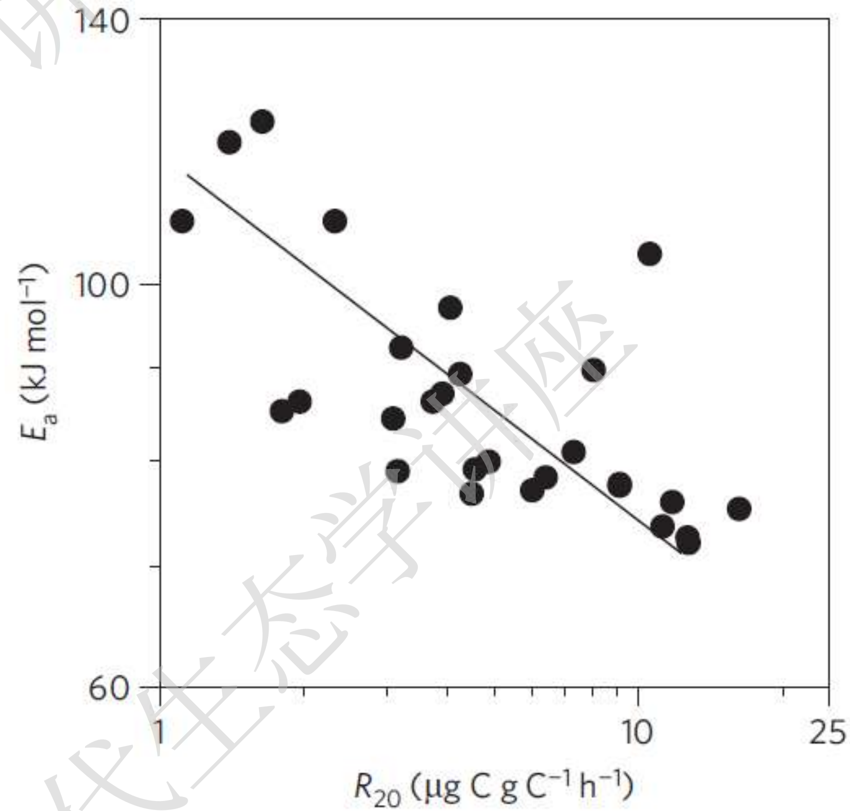
NATURE 2005



Fierer et al. 2005 Ecology

Reichstein et al. 2005 BioGeoSci

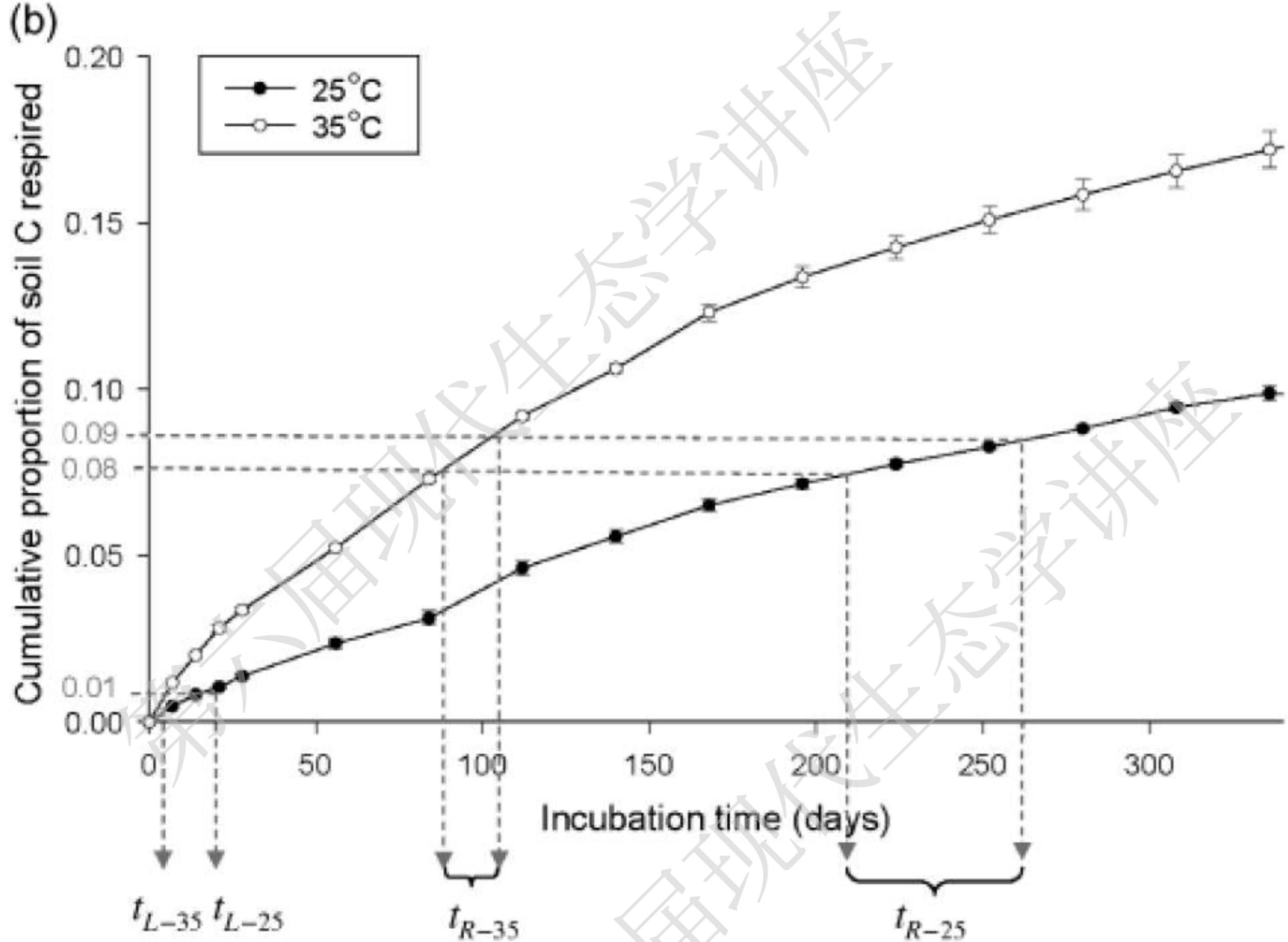




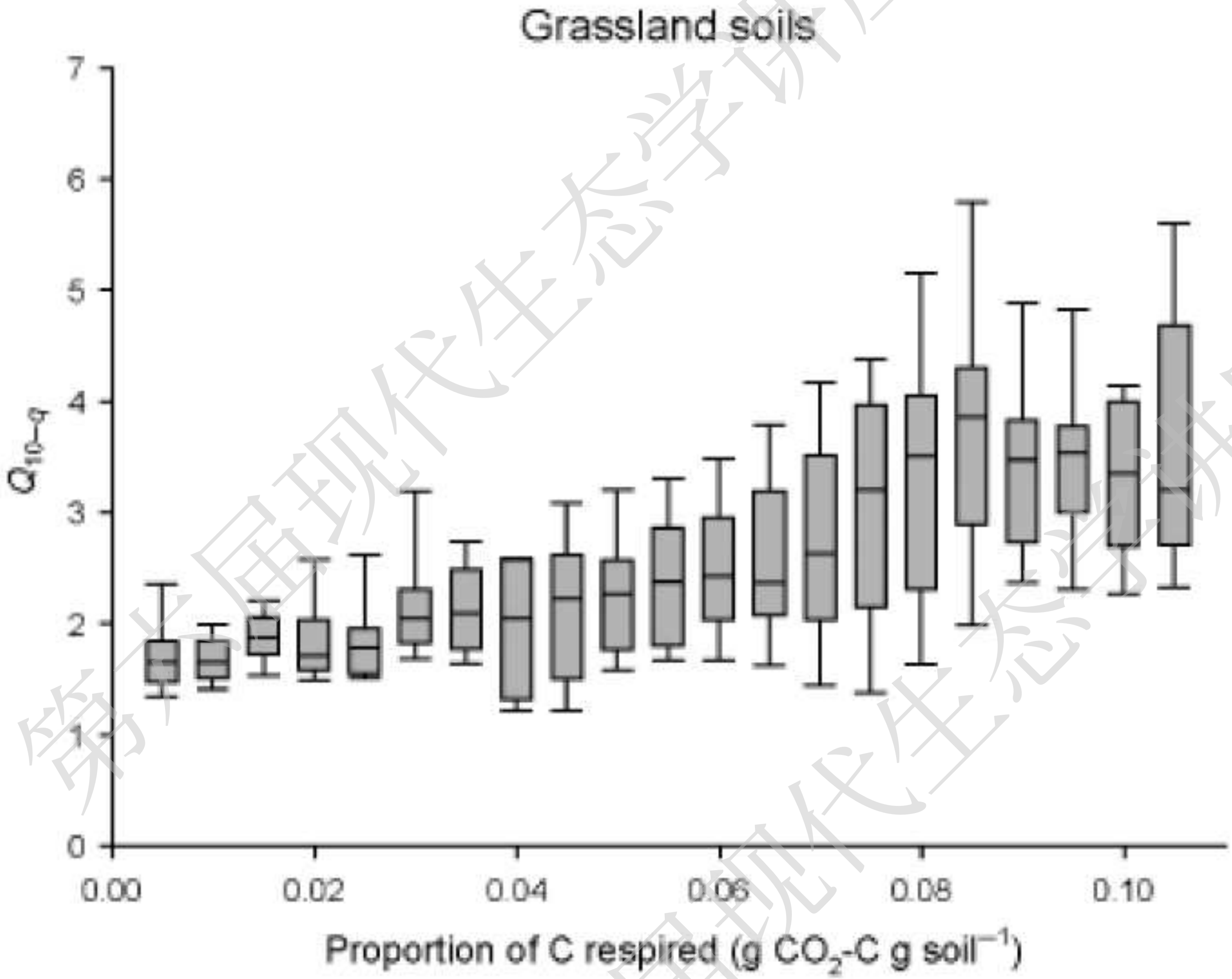
LETTERS
PUBLISHED ONLINE: 14 NOVEMBER 2010 | DOI: 10.1038/NGEO1009
nature geoscience

Widespread coupling between the rate and temperature sensitivity of organic matter decay

Joseph M. Craine[1]*, Noah Fierer[2,3] and Kendra K. McLauchlan[4]



Conant et al. 2008 GCB



Conant et al. 2008 GCB

Temperature sensitivity increases with soil organic carbon recalcitrance along an elevational gradient in the Wuyi Mountains, China

Xia Xu[a,b], Yan Zhou[a,c], Honghua Ruan[a,*], Yiqi Luo[b], Jiashe Wang[d]

Soil Biology & Biochemistry 42 (2010) 1811–1815

Temperature sensitivity of soil carbon fractions in boreal forest soil

Kristiina Karhu,[1] Hannu Fritze,[2] Kai Hämäläinen,[3] Pekka Vanhala,[1] Högne Jungner,[3] Markku Oinonen,[3] Eloni Sonninen,[3] Mikko Tuomi,[1] Peter Spetz,[2] Veikko Kitunen,[2] and Jari Liski[1,4]

[1] *Finnish Environment Institute, Research Programme for Global Change, P.O. Box 140, FI-00251 Helsinki, Finland*

Ecology, 91(2), 2010, pp. 370–376

"We show that the temperature sensitivity of decomposition increases remarkably from the youngest annually cycling fraction (Q_{10} < 2) to a decadally cycling one (Q_{10} = 4.2–6.9) but decreases again to a centennially cycling fraction (Q_{10} = 2.4–2.8) in boreal forest soil."

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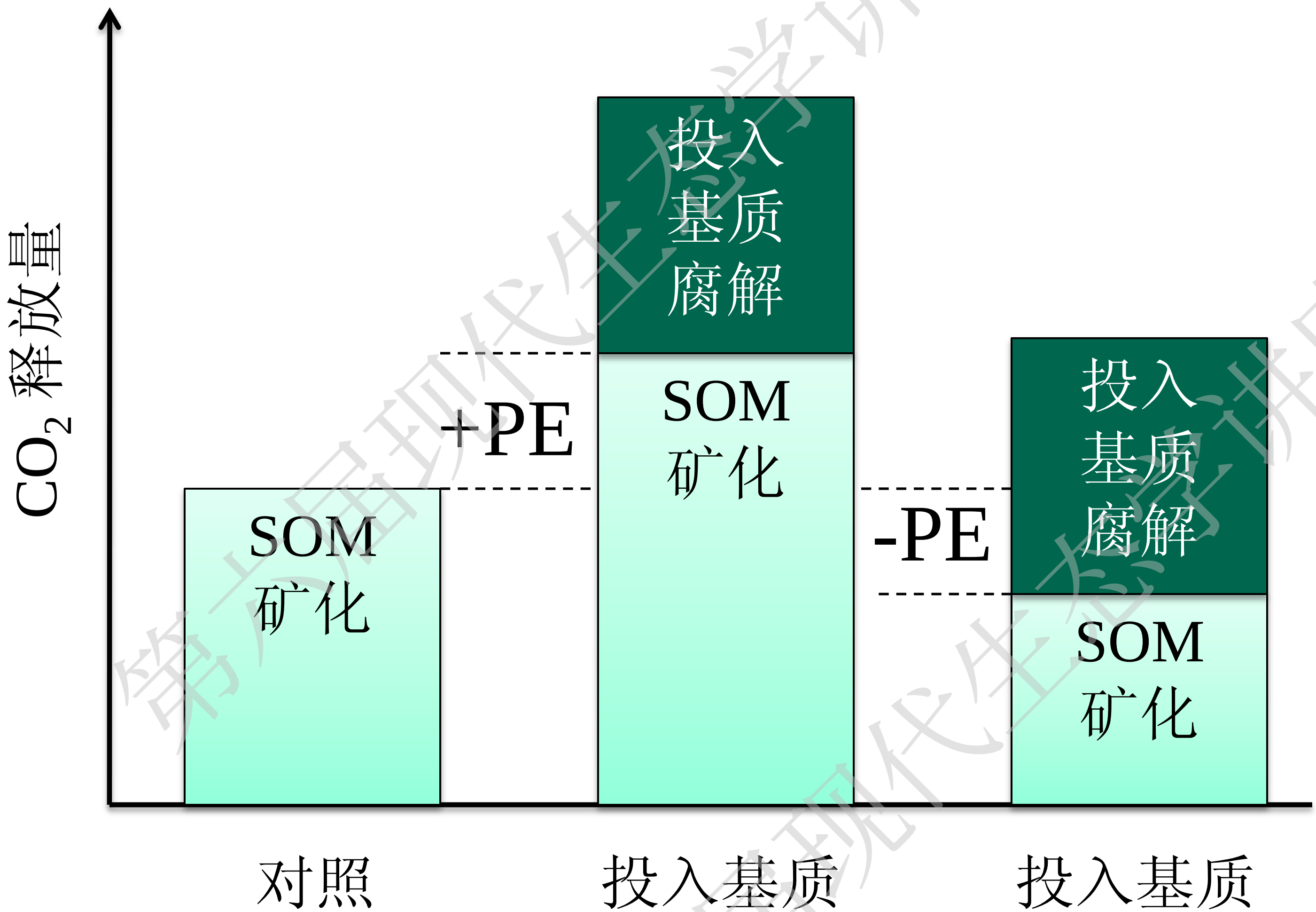
第六届现代生态学讲座

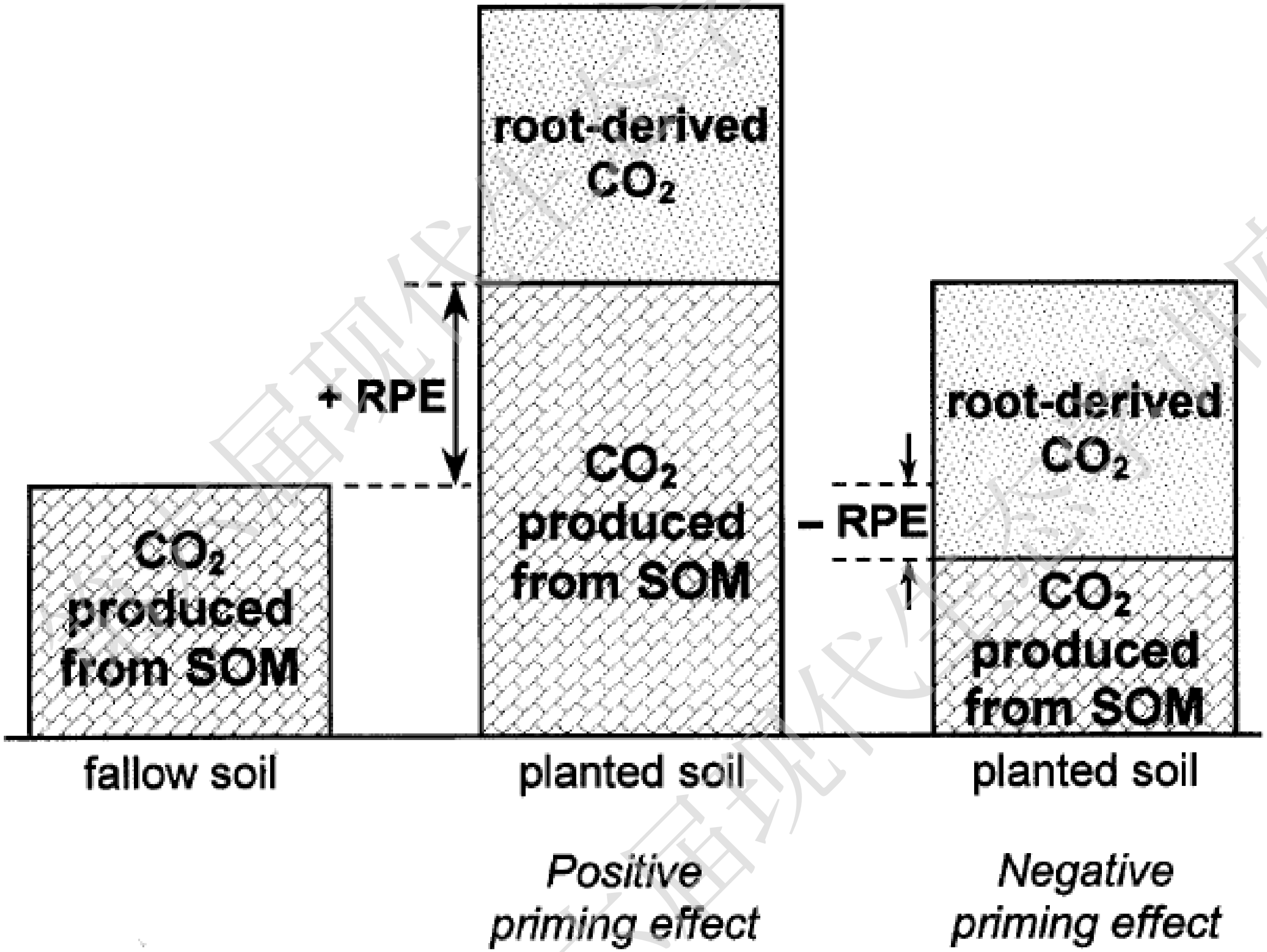
什么是激活效应？



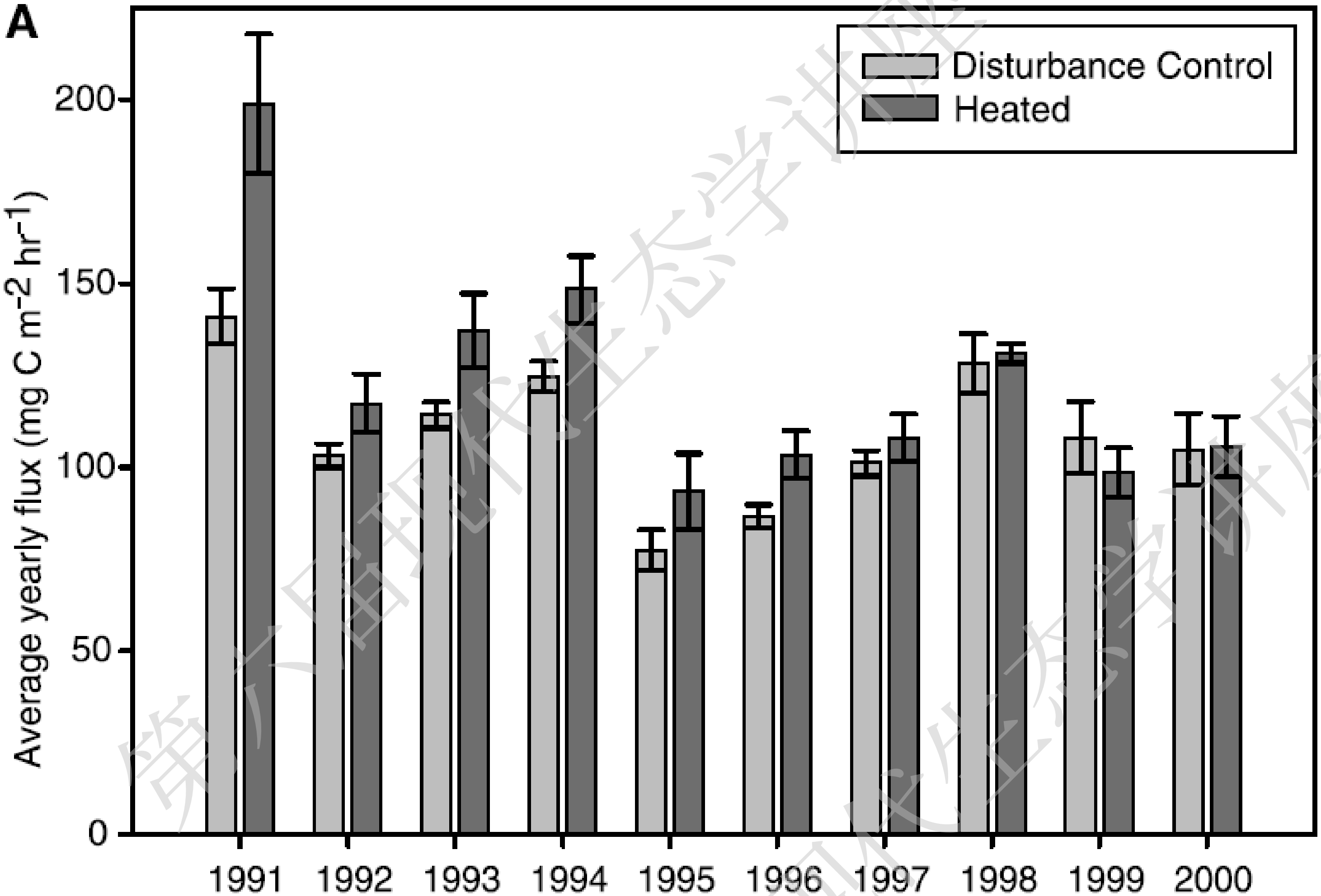
参照 Kuzyakov, Y. 2002. J. Plant Nutr. Soil Sci.

+PE：正激活效应；　-PE：负激活效应

什么是根际激活效应？



From: Kuzyakov, Y. 2002. J. Plant Nutr. Soil Sci.



Soil Warming and Carbon-Cycle Feedbacks to the Climate System

J. M. Melillo,[1]* P. A. Steudler,[1] J. D. Aber,[2] K. Newkirk,[1] H. Lux,[1]
F. P. Bowles,[3] C. Catricala,[1] A. Magill,[2] T. Ahrens,[1] S. Morrisseau[1]

SCIENCE 2002

13 AUGUST 2010 VOL 329 SCIENCE

Global Convergence in the Temperature Sensitivity of Respiration at Ecosystem Level

Miguel D. Mahecha,[1,2]* Markus Reichstein,[1] Nuno Carvalhais,[1,3] Gitta Lasslop,[1] Holger Lange,[4] Sonia I. Seneviratne,[2] Rodrigo Vargas,[5] Christof Ammann,[6] M. Altaf Arain,[7] Alessandro Cescatti,[8] Ivan A. Janssens,[9] Mirco Migliavacca,[10] Leonardo Montagnani,[11,12] Andrew D. Richardson[13]

The respiratory release of carbon dioxide (CO_2) from the land surface is a major flux in the global carbon cycle, antipodal to photosynthetic CO_2 uptake. Understanding the sensitivity of respiratory processes to temperature is central for quantifying the climate–carbon cycle feedback. We approximated the sensitivity of terrestrial ecosystem respiration to air temperature (Q_{10}) across 60 FLUXNET sites with the use of a methodology that circumvents confounding effects. Contrary to previous findings, our results suggest that Q_{10} is independent of mean annual temperature, does not differ among biomes, and is confined to values around 1.4 ± 0.1. The strong relation between photosynthesis and respiration, by contrast, is highly variable among sites. The results may partly explain a less pronounced climate–carbon cycle feedback than suggested by current carbon cycle climate models.

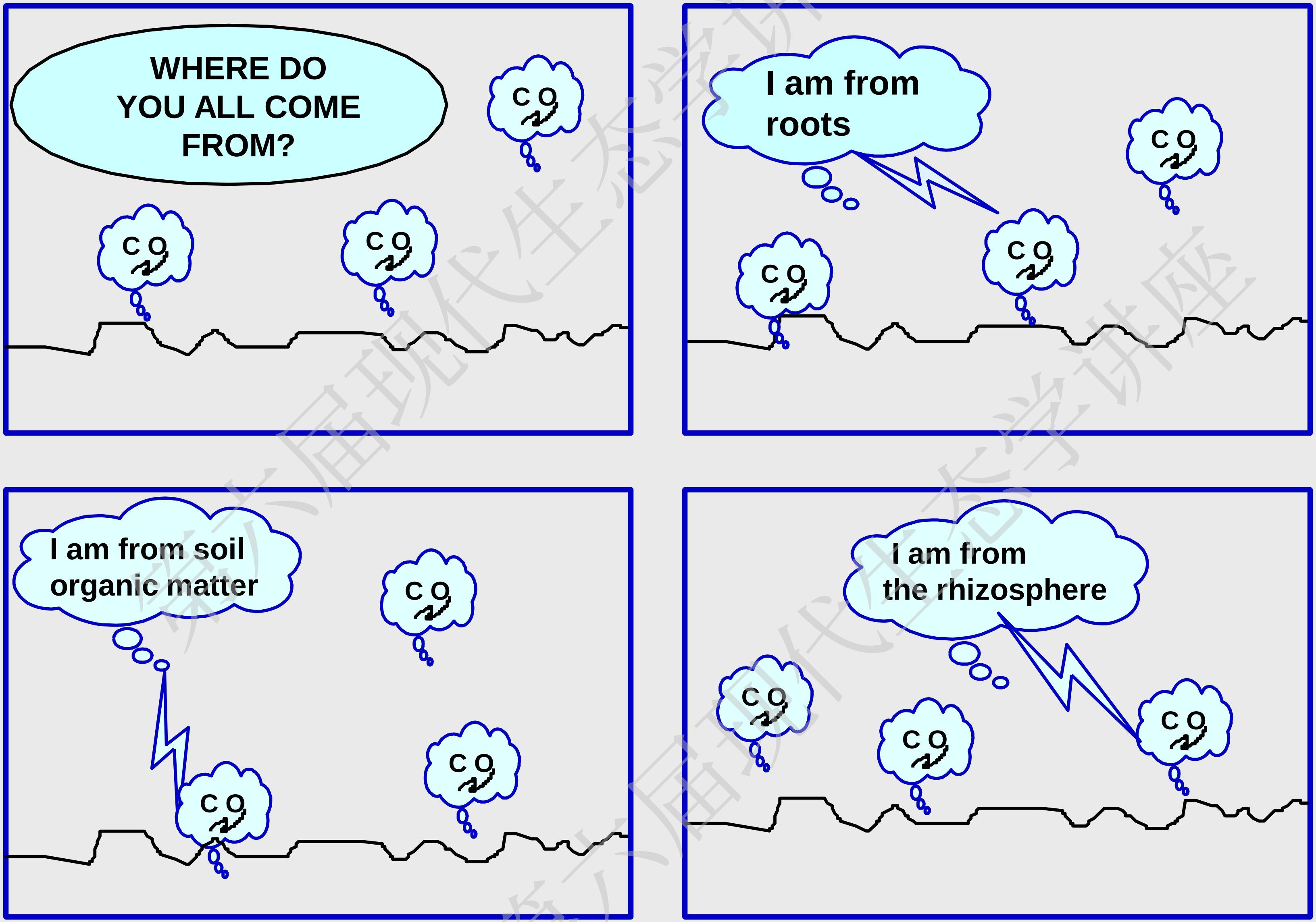
Table 1 R^2 and Q_{10} values for the relationship between soil respiration and temperature

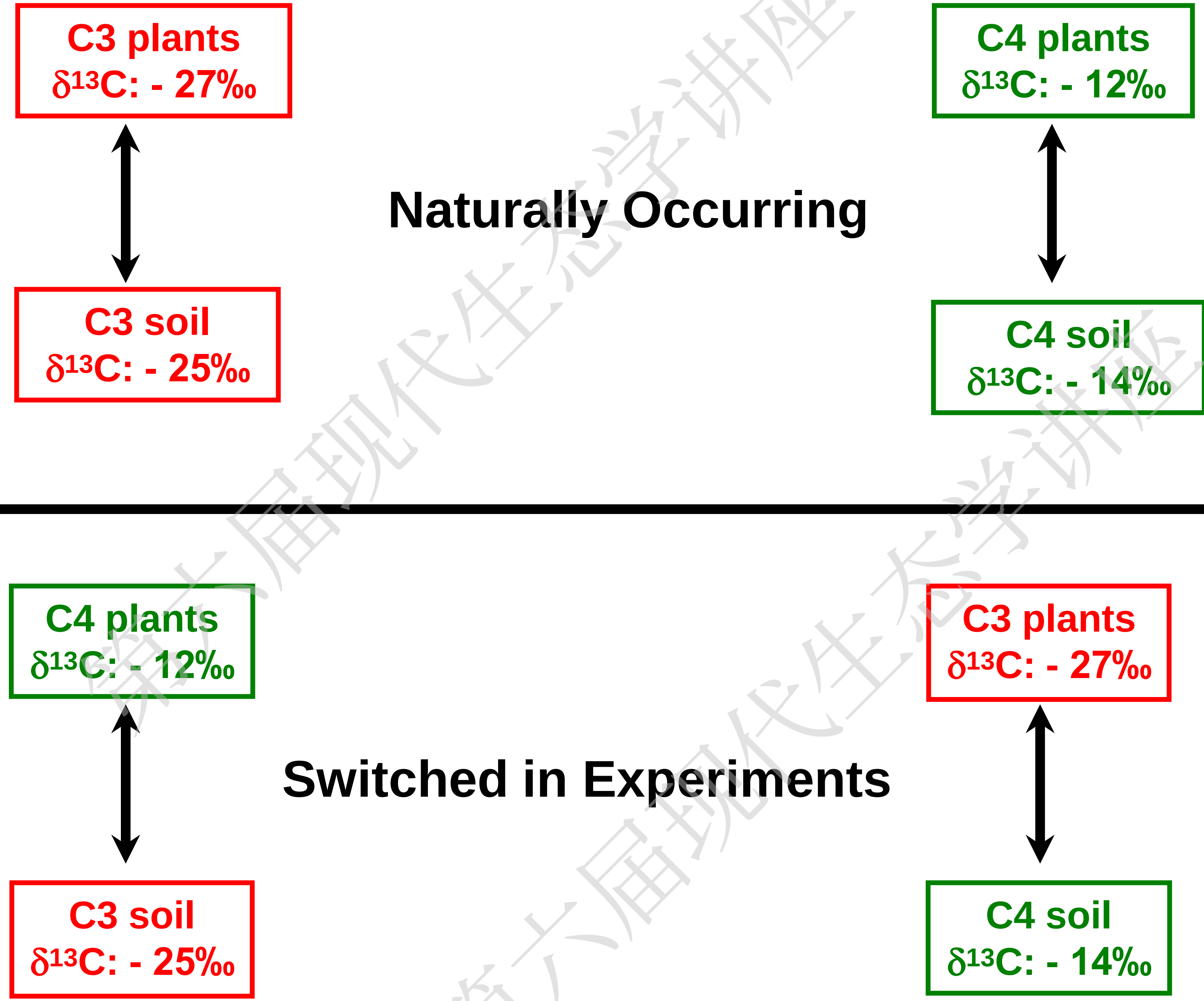
Treatment	R^2	Q_{10}
Control	0.91	3.5 (0.4)
Double litter	0.90	3.4 (0.4)
No litter	0.91	3.1 (0.3)
No roots	0.73	2.5 (0.4)
No inputs	0.89	2.3 (0.2)
OA-less	0.82	2.6 (0.3)
'Roots'	0.95	4.6 (0.5)

For R^2 values; $P < 0.01$; Q_{10} values are means (± s.e.m.). Q_{10} values were obtained from the exponential curve of the form $y = \beta_0 e^{\beta_1 T}$, where $Q_{10} = e^{10 \times \beta_1}$. Standard error for Q_{10} is calculated as $Q_{10} \times 10 \times$ s.e.(β).

Boone et al. 1998 NATURE

第六届现代生态学讲座


WHERE DO YOU ALL COME FROM?
I am from roots
I am from soil organic matter
I am from the rhizosphere


C3 plants
δ13C: - 27‰
C3 soil
δ13C: - 25‰
Naturally Occurring
C4 plants
δ13C: - 12‰
C4 soil
δ13C: - 14‰
C4 plants
δ13C: - 12‰
C3 soil
δ13C: - 25‰
Switched in Experiments
C3 plants
δ13C: - 27‰
C4 soil
δ13C: - 14‰

Continuous ^{13}C-labeling Greenhouse at UCSC

$[CO_2] = 400$ ppm
$\delta^{13}C = -17‰$

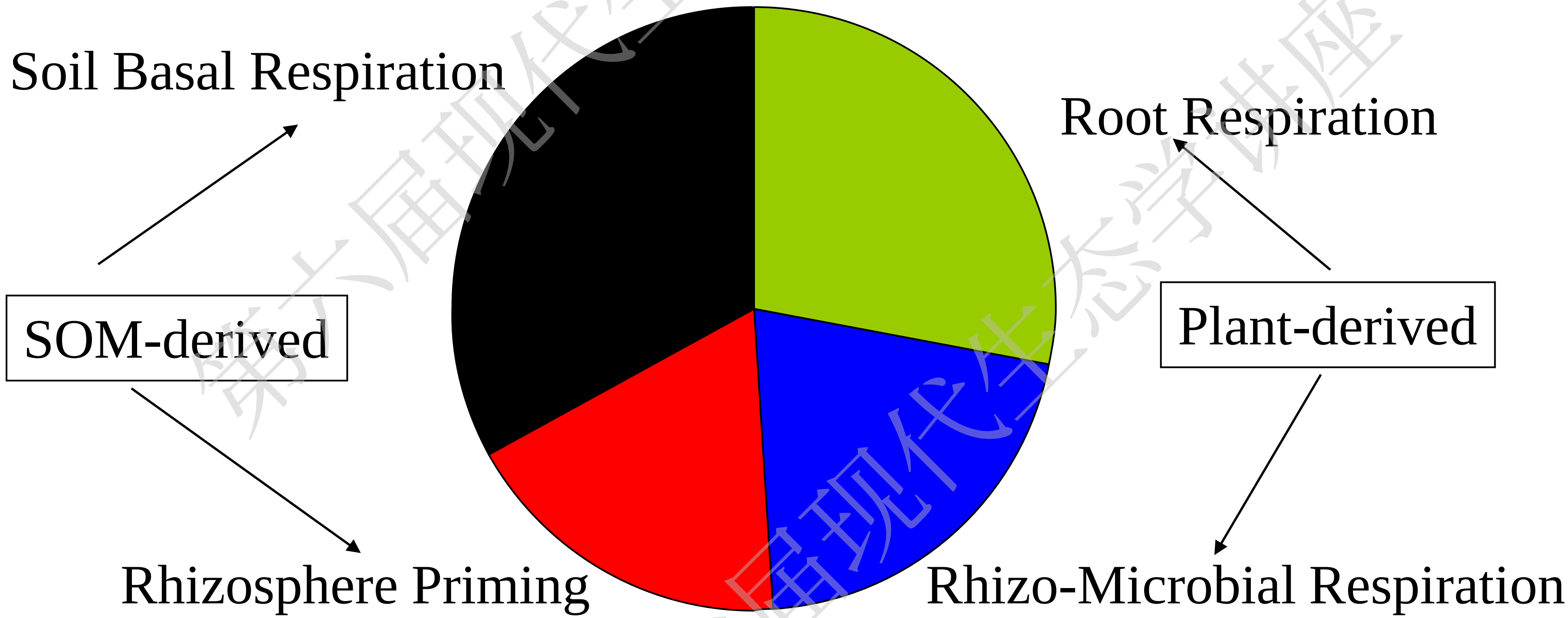
Magnitude of the rhizosphere effect on SOM decomposition measured by isotope methods (Based on Cheng and Kuzyakov 2005).

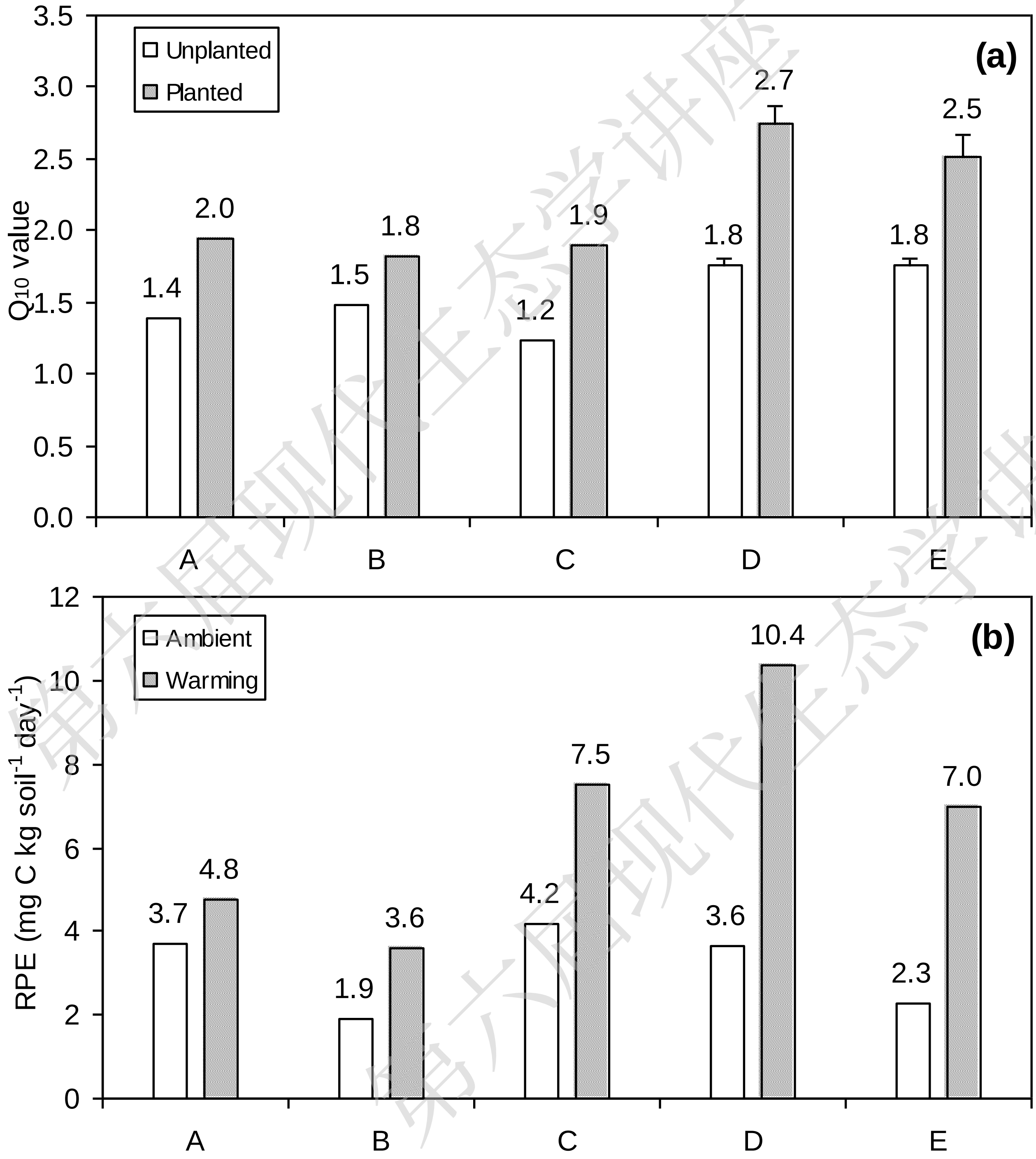
Plant Type	**Treatment**	**Soil Type[1]**	**PGC[2]**	**%Priming[3]**	**Time[4](d)**	**Reference**
Wheat		CLO	GC	**-37**	16	Cheng 96
Wheat	Ambient CO_2	CLK	GC	44	28	Cheng & Johnson 98
Wheat	Elevated CO_2	CLK	GC	17	28	Cheng & Johnson 98
Wheat	Ambient CO_2, +N	CLK	GC	42	28	Cheng & Johnson 98
Wheat	Elevated CO_2, +N	CLK	GC	73	28	Cheng & Johnson 98
Sunflower	Ambient CO_2	CLK	GH	55	53	Cheng et al. 00
Sunflower	Elevated CO_2	CLK	GH	31	53	Cheng et al. 00
Wheat	12/12 hrs light/dark	CLK	GC	100	38	Kuzyakov & Cheng 01
Wheat	12/60 hrs light/dark	CLK	GC	**-50**	38	Kuzyakov & Cheng 01
Soybean	Growing season mean	CLK	GH	70	120	Fu & Cheng 02
Sunflower	Growing season mean	CLK	GH	39	120	Fu & Cheng 02
Sorghum	Growing season mean	SLC	GH	**-9**	120	Fu & Cheng 02
Amaranthus	Growing season mean	SLC	GH	**-5**	120	Fu & Cheng 02
Soybean		CLK	GH	3	35	Cheng et al. 03
Wheat		CLK	GH	7	35	Cheng et al. 03
Soybean		CLK	GH	382	68	Cheng et al. 03
Wheat		CLK	GH	287	68	Cheng et al. 03
Soybean		CLK	GH	312	89	Cheng et al. 03
Wheat		CLK	GH	130	89	Cheng et al. 03
Soybean		CLK	GH	254	110	Cheng et al. 03
Wheat		CLK	GH	60	110	Cheng et al. 03
Soybean	Growing season mean	CLK	GH	164	119	Cheng et al. 03
Wheat	Growing season mean	CLK	GH	96	119	Cheng et al. 03

%priming is calculated as: (planted - unplanted)/unplanted **X** 100.

基于过去二十多年的研究结果，我们发现根际激活效应的变化幅度在 -50% 到+380% 之间，可以与土壤温度或者水分对土壤有机质矿化速率的影响相提并论。

Which component of the total soil respiration is more sensitive to warming?





Zhu & Cheng 2011, Global Change Biology

In summary, rhizosphere priming may increase the temperature sensitivity of SOM decomposition.

How will soil organic C pool respond to global warming?

1. General temperature sensitivity of SOM decomposition
   Conclusion-I: it is still controversial.

2. Substrate availability vs. T-sensitivity
   Conclusion-II: substrate availability is an important factor.

3. T-sensitivity of labile vs. recalcitrant SOM decomposition
   Conclusion-III: it is inconclusive.

4. Rhizosphere interactions vs. T-sensitivity
   Conclusion-IV: rhizosphere processes modulate T-sensitivity.

5. What's next? More research is needed.

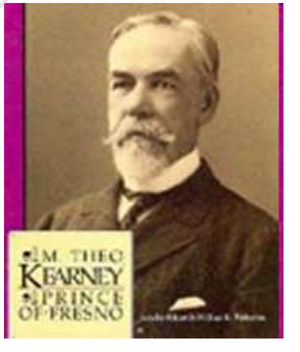
Acknowledgements

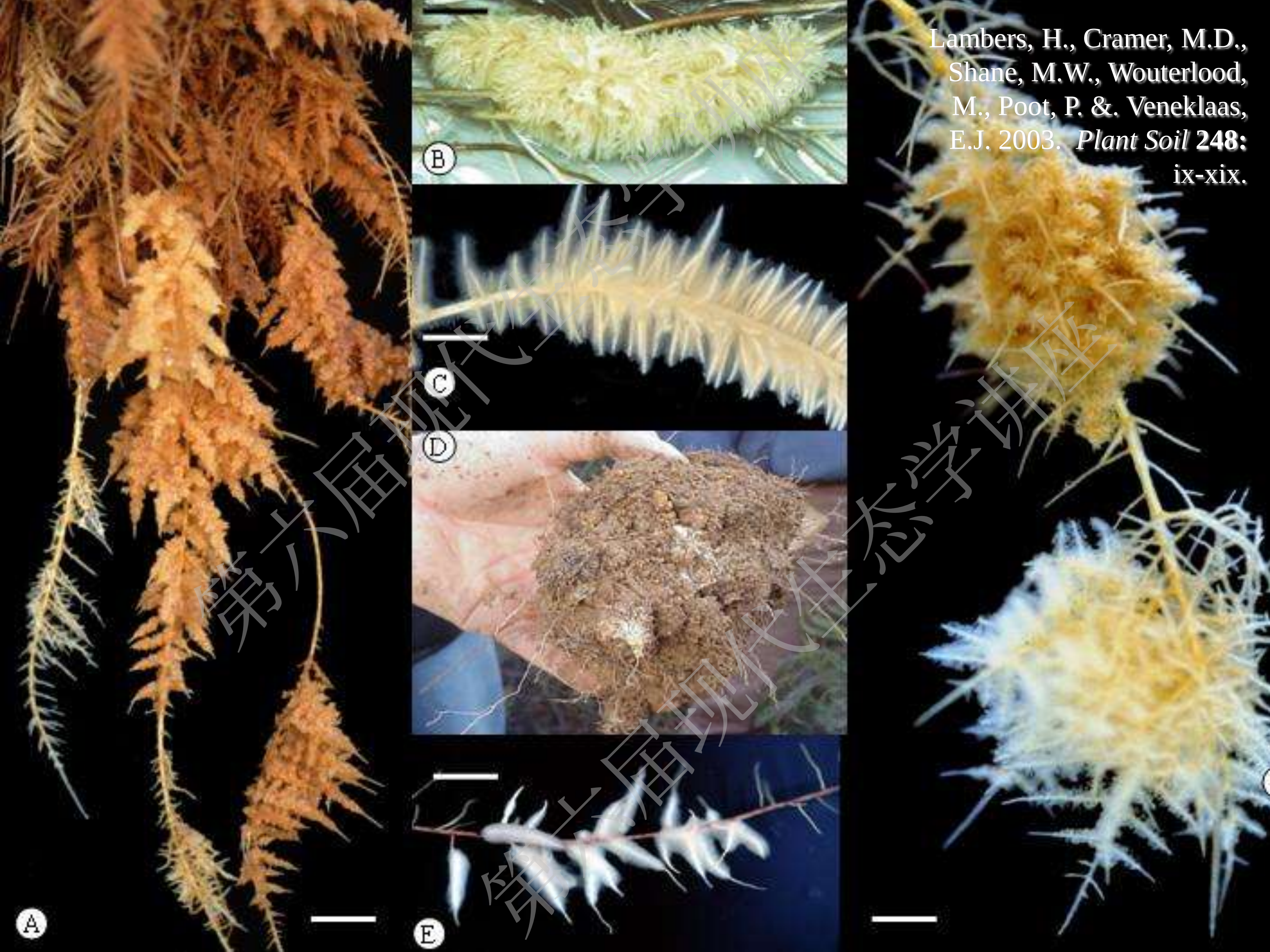
Thanks to Feike Dijkstra, Nick Bader, Daniel Keck, and Biao Zhu for doing the work.

Dyke Andreasen & David Harris analyzed all samples for isotopes.

Many undergraduate students provided assistance.

USDA NRI program (Grant # 2006-35107-17225) and Kearney Foundation of Soil Science provided the funding.





Lambers, H., Cramer, M.D., Shane, M.W., Wouterlood, M., Poot, P. & Veneklaas, E.J. 2003. *Plant Soil* **248:** ix-xix.

Biogeochemistry

Soil warming and organic carbon content

Soils store two or three times more carbon than exists in the atmosphere as CO_2, and it is thought that the temperature sensitivity of decomposing organic matter in soil partly determines how much carbon will be transferred to the atmosphere as a result of global warming[1]. Giardina and Ryan[2] have questioned whether turnover times of soil carbon depend on temperature, however, on the basis of experiments involving isotope analysis and

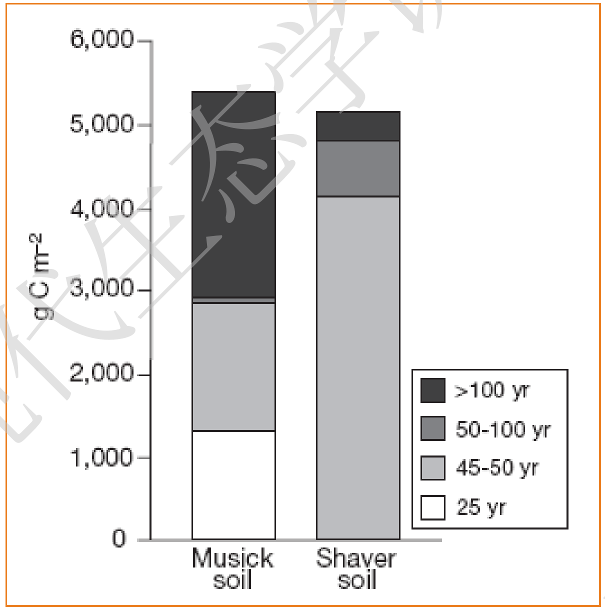


Figure 1 Radiocarbon estimates of turnover times of carbon fractions of two soils on an elevational gradient with similar parent material, vegetation and disturbance history[12]. Fractions were separated by density and hydrolysis for each soil depth[12]. The CO_2 that would be evolved during one-year incubations (98 and 92 g C m^{-2} yr^{-1} for Musick and Shaver soils, respectively) was calculated from carbon stocks and turnover times. Dividing respired CO_2 by total soil carbon, as Giardina and Ryan[2] do in their one-pool model, yields nearly identical turnover times estimates for the two soils (53 and 54 yr for Musick and Shaver soils, respectively). However, the cooler Shaver soil contains twice as much carbon with turnover times of about 50 yr and the warmer Musick soil has a small but important pool that cycles more rapidly.

Eric A. Davidson*, Susan E. Trumbore†, ‡Ronald Amundson

NATURE 2000

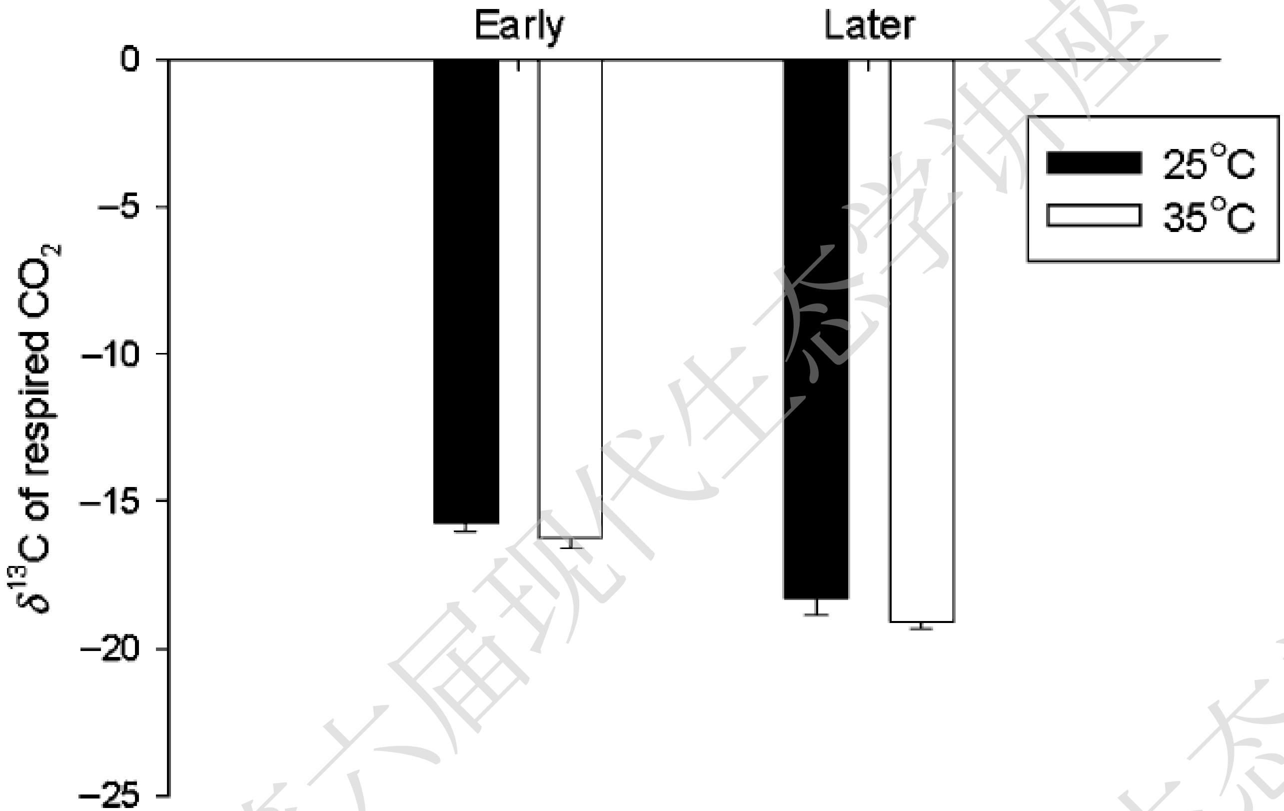


Fig. 2 ^{13}C signature of CO_2 evolved from Brazilian pasture soils incubated at 25 and 35 °C early during incubation (cumulative CO_2-C respiration equivalent to 2% of initial soil C; $P = 0.219$, $n = 3$) or later (respiration of the same mass of CO_2-C, but after the equivalent of 6% of initial soil C had already been respired; $P = 0.270$, $n = 3$). Error bars indicate standard errors estimated from four replicates.

Conant et al. 2008 GCB