Stable isotopes in hydrology and ecology

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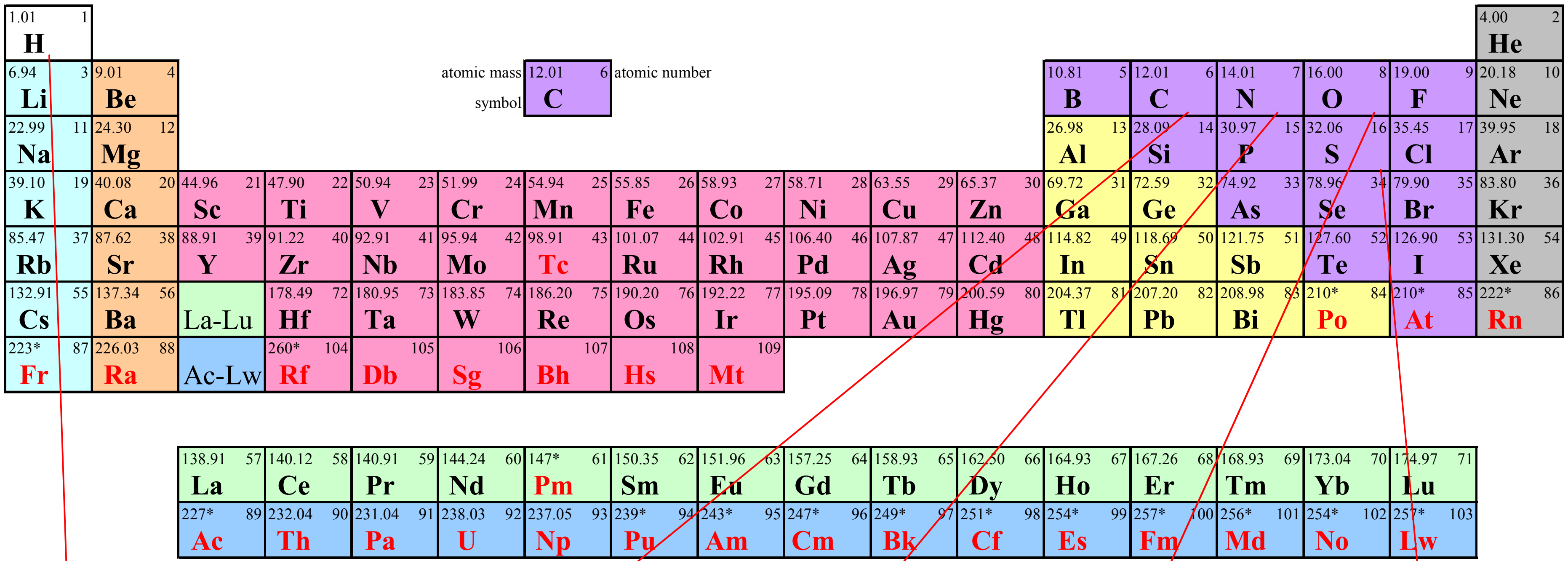
Most important isotopes in biogeochemistry



H		
	^{1}H	99.985%
	^{2}H	0.015%
	^{3}H	(radioactive)

C		
	^{12}C	99.89%
	^{13}C	0.11%
	^{14}C	(radioactive)

N		
	^{14}N	99.634%
	^{15}N	0.366%

O		
	^{16}O	99.759%
	^{17}O	0.037%
	^{18}O	0.204%

S		
	^{32}S	95.00%
	^{33}S	0.76%
	^{34}S	4.22%
	^{36}S	0.014%

Standards and δ notation

H	VSMOW Vienna Standard Mean Ocean Water	$^{2}H = 0.01558\%$
C	PDB Pee Dee Belemnite	$^{13}C = 1.12372\%$
N	air	$^{15}N = 0.3663\%$
O	VSMOW Vienna Standard Mean Ocean Water	$^{18}O = 0.20052\%$

attention: 2 definitions coexist, either on isotope ratio R or on isotope fraction F

$$\delta\ ^{15}N = \frac{R_{sample}}{R_{standard}} - 1 \qquad \text{where:} \quad R = \frac{^{15}N}{^{14}N} \qquad R_{standard} = 0.0036765$$

$$\delta\ ^{15}N = \frac{F_{sample}}{F_{standard}} - 1 \qquad \text{where:} \quad F = \frac{^{15}N}{^{14}N + {}^{15}N} \qquad F_{standard} = 0.003663$$

δ usually expressed in ‰

Three main types of applications

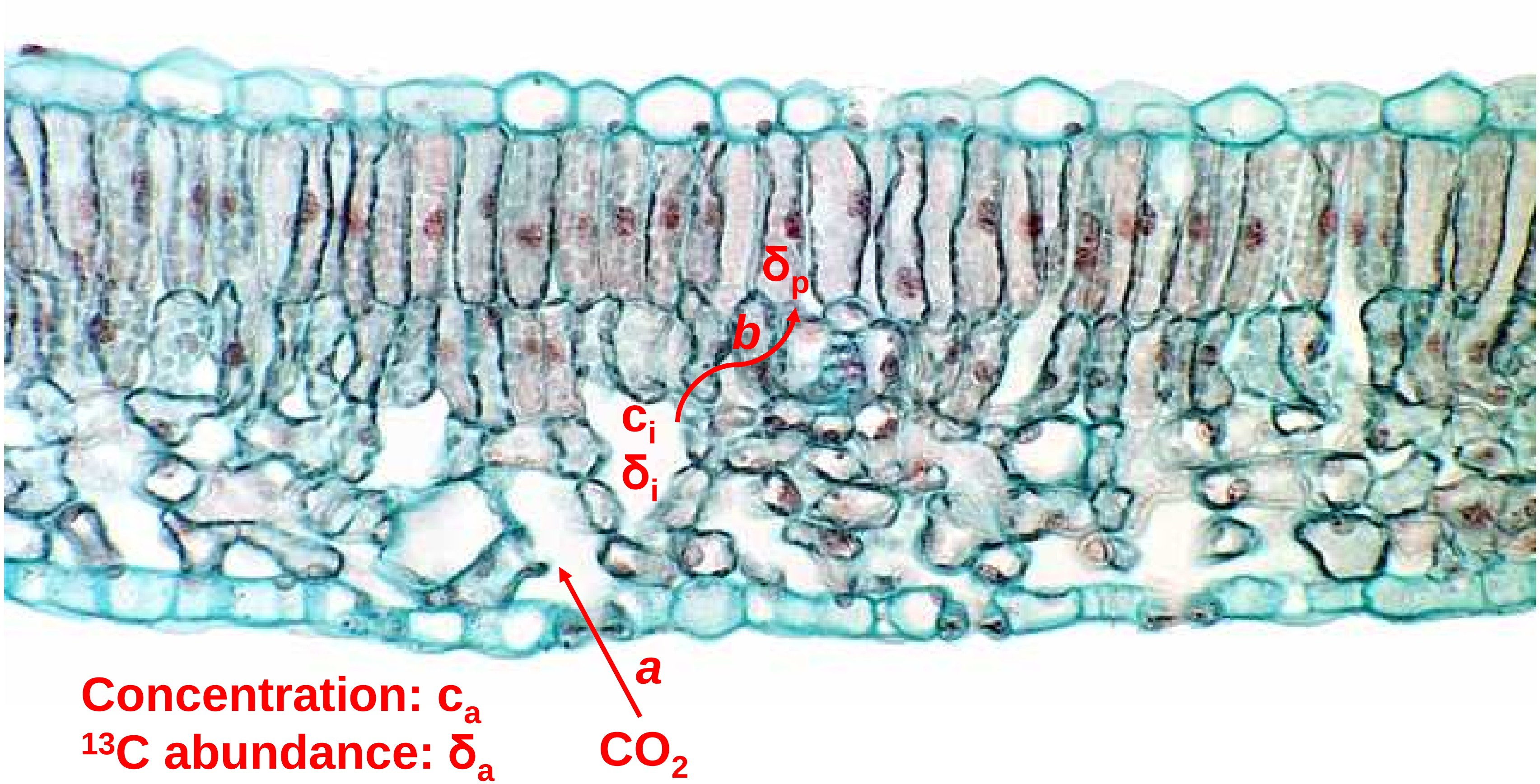
- **Process studies through natural isotope fractionation**

fractionation: differential behaviour between isotopes in (bio-)chemical or physical processes => abundance in product ≠ substrate (only in open systems with branched reaction pathways)

- **Tracing of natural sources with contrasting abundances**

- **Experimental labelling and tracing**

Example 1: C fractionation during C3 photosynthesis



Photograph: Michael Clayton

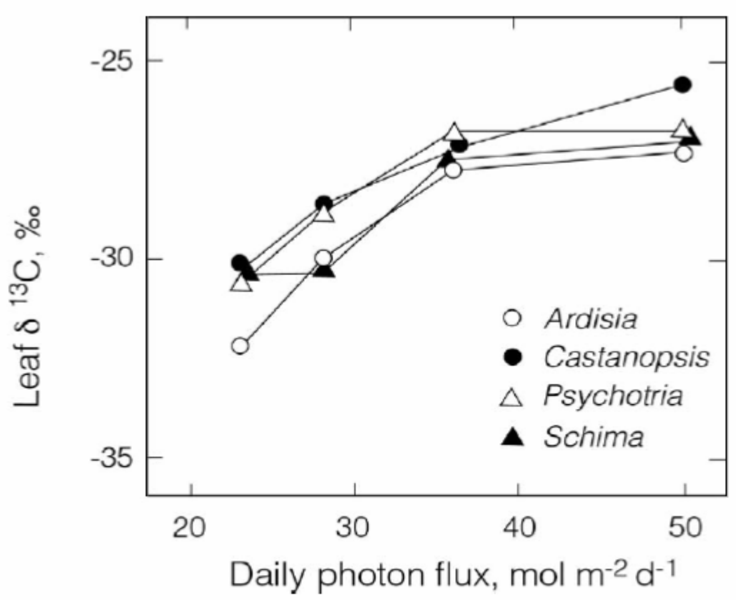
a: **diffusion => physical fractionation ≈ 4.4‰**

b: **Rubisco => enzymatic fractionation ≈ 27‰**

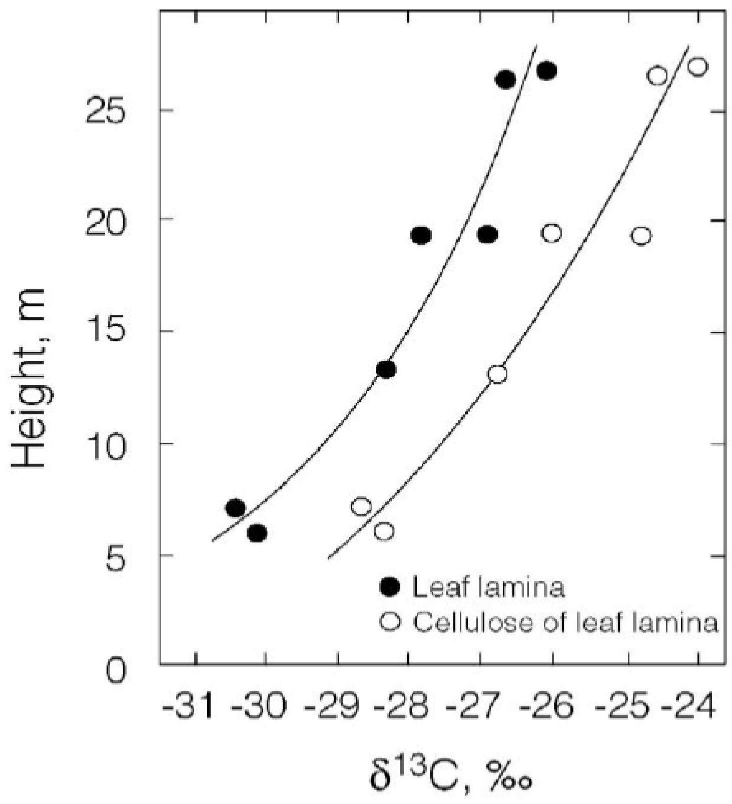
$\Delta = \delta_a - \delta_p = a + (b-a)\, c_i / c_a$

active photosynthesis + stomatal closure => $c_i\downarrow$ => $\Delta\downarrow$ => $\delta_p\uparrow$

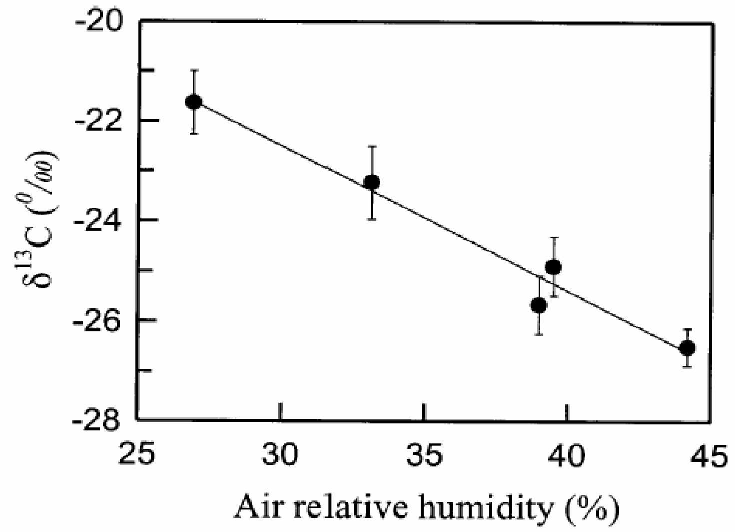
Example 1: C fractionation in C3 plants



Ehleringer *et al.*, 1986:
^{13}C in leaves vs. light intensity

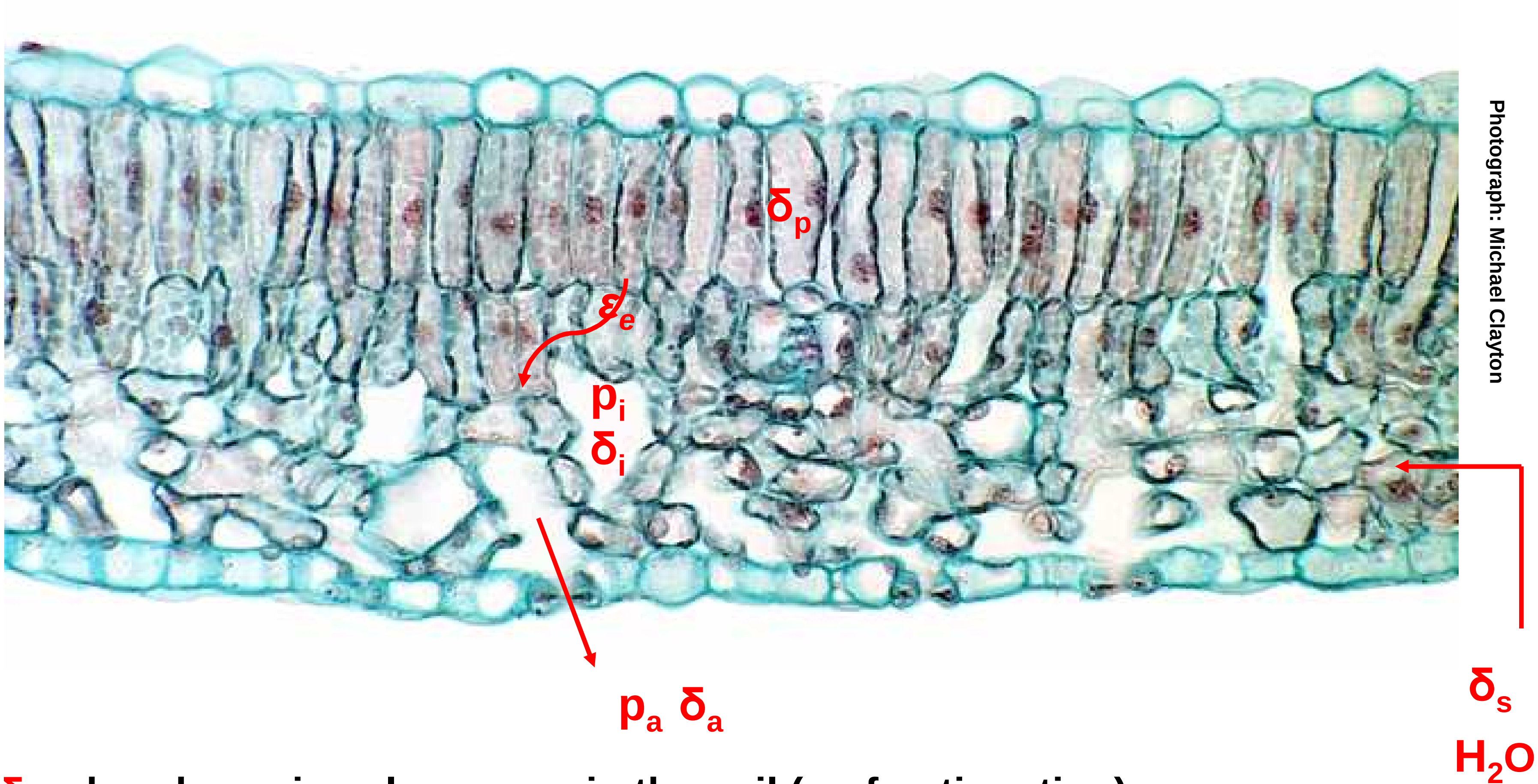


Leavitt & Long, 1982: ^{13}C in leaves vs. tree height



Ekblad & Högberg, 2001: forest soil respiration vs. air humidity 1-4 days before

Example 2: O fractionation during transpiration

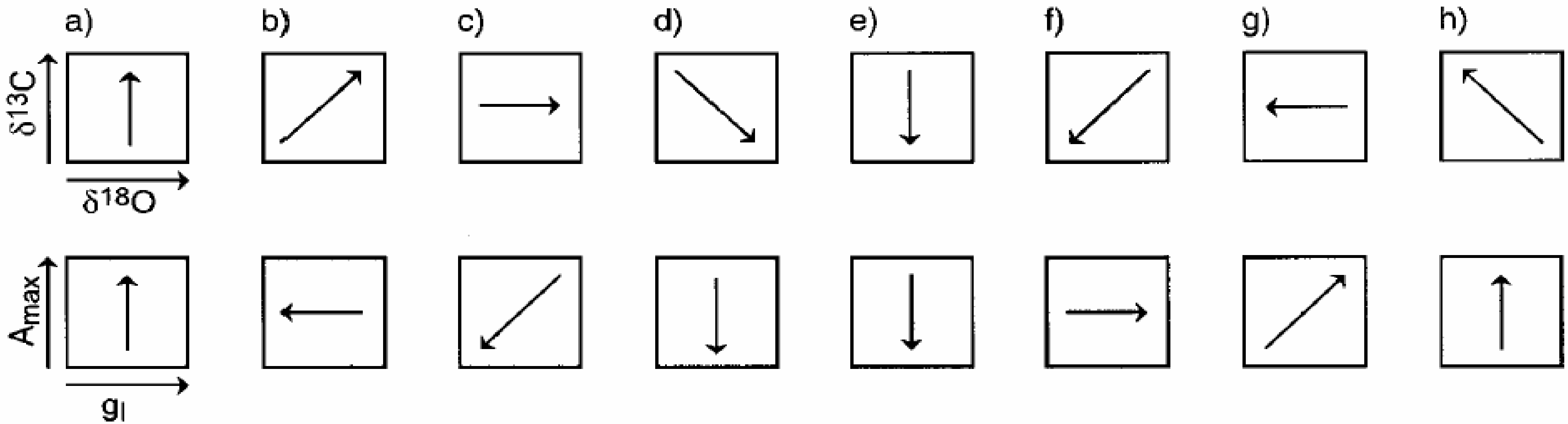


δ_s: abundance in xylem sap = in the soil (no fractionation)
ε_e: evaporation => equilibrium fractionation
ε_k: diffusion to free atmosphere => kinetic fractionation

Examples 1+2: combining ^{13}C and ^{18}O

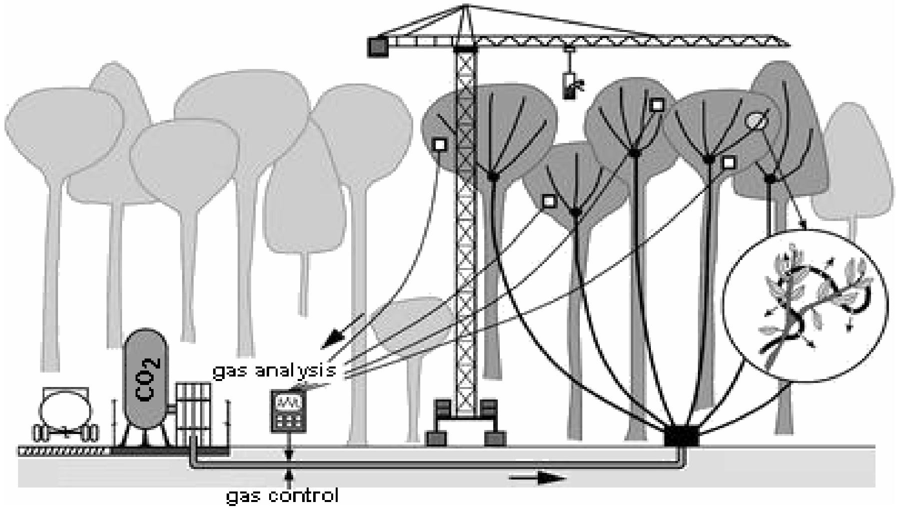
2 unknown variables: photosynthesis A_{max} and stomatal conductance g_l

=> 2 independent measures necessary: $\delta^{13}C$ and $\delta^{18}O$ in leaves



Scheidegger *et al.*, 2000

Tracing of sources with naturally contrasting abundances: the Swiss canopy crane experiment



CO_2 enrichment in tree crowns

CO_2 originates from fossil fuel and is naturally depleted in ^{13}C

Tracing of sources with naturally contrasting abundances

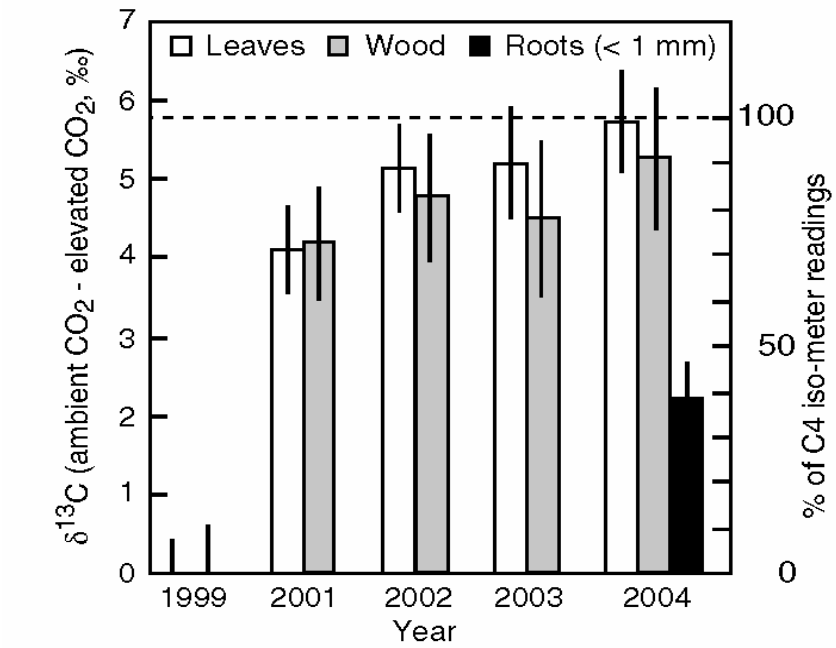
C goes from ^{13}C-depleted

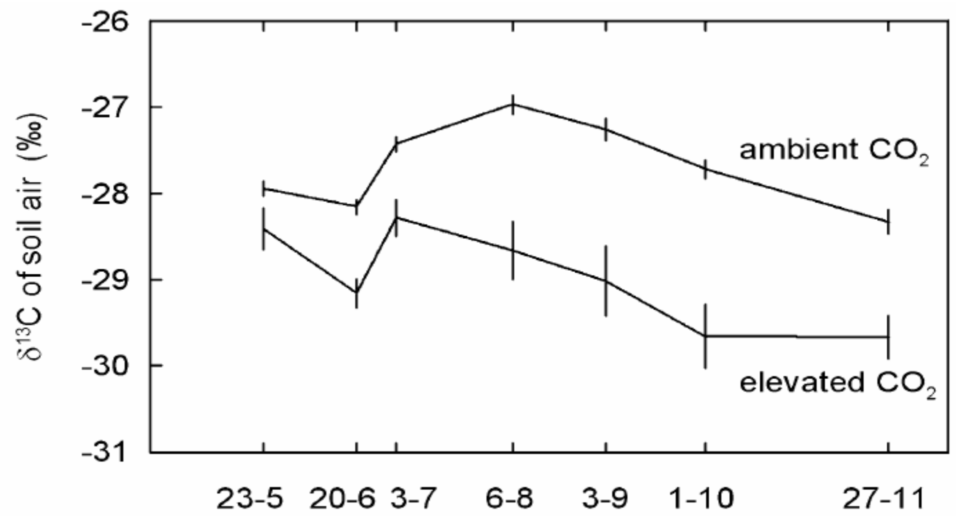
CO_2 to...

trees...

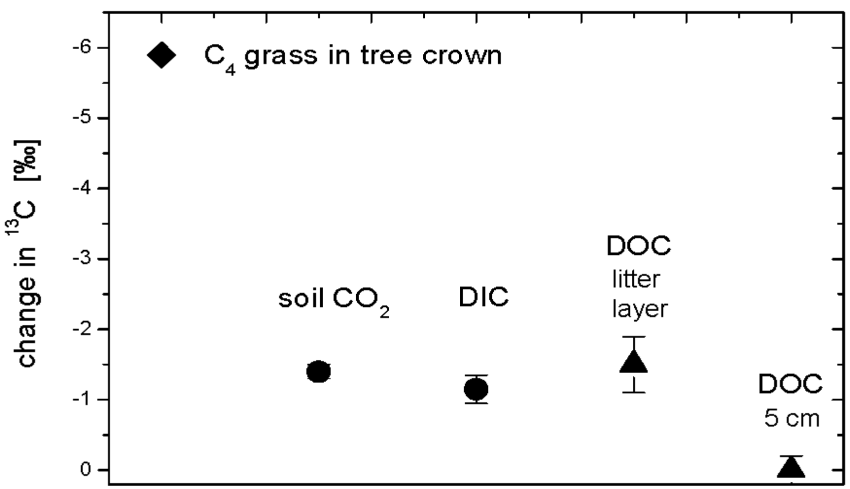
and soil

Körner *et al.*, 2005





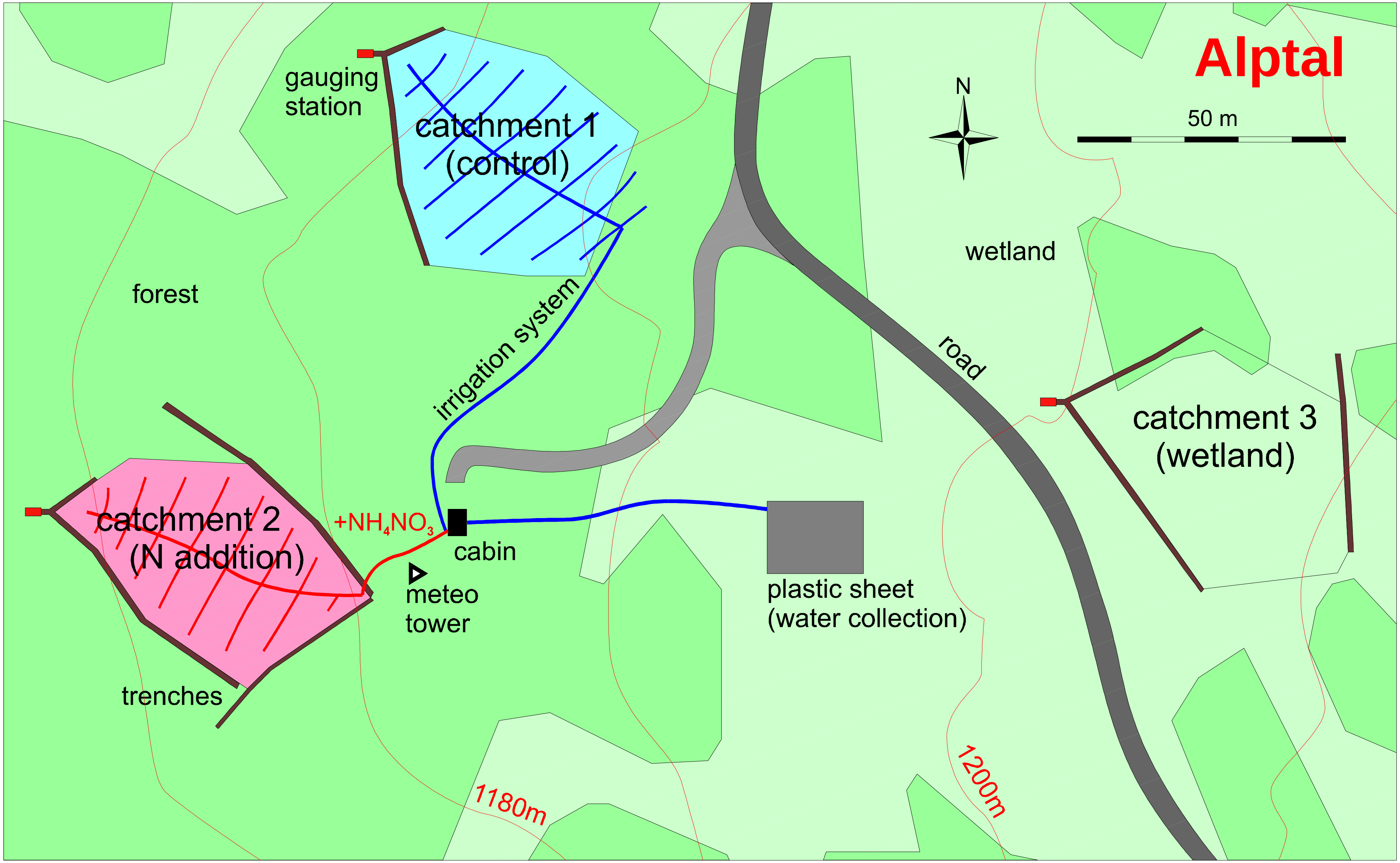
Steinmann *et al.*, 2004



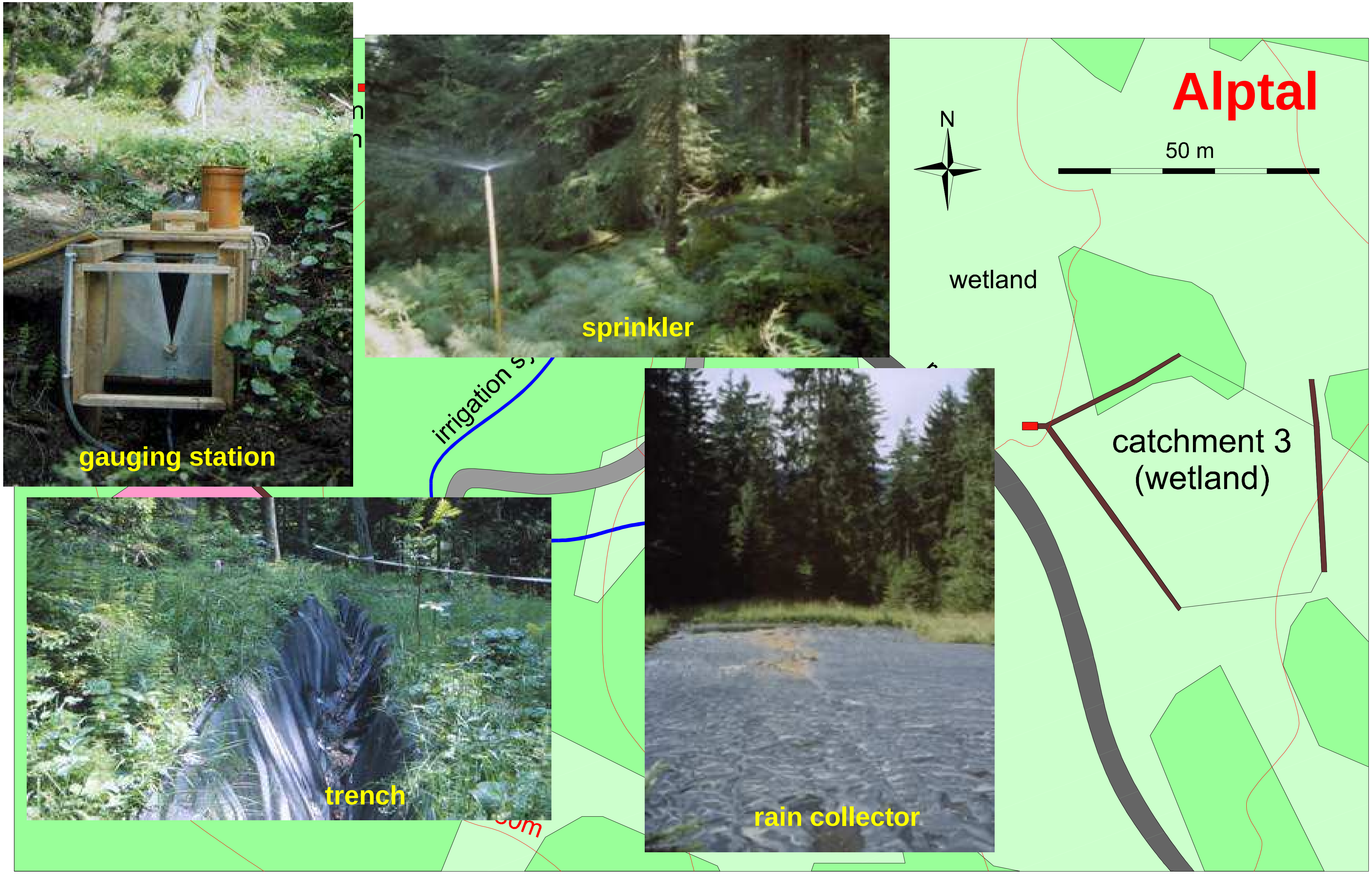
Isotopes are powerful tracers
... even if labelling water at
Pass Lunghin* will not allow to
detect the signal in the Danube
in Vienna

*where the basins of Black Sea (Danube), North Sea (Rhine) and Mediterranean (Po) come together

Experimental tracer application: NITREX experiments

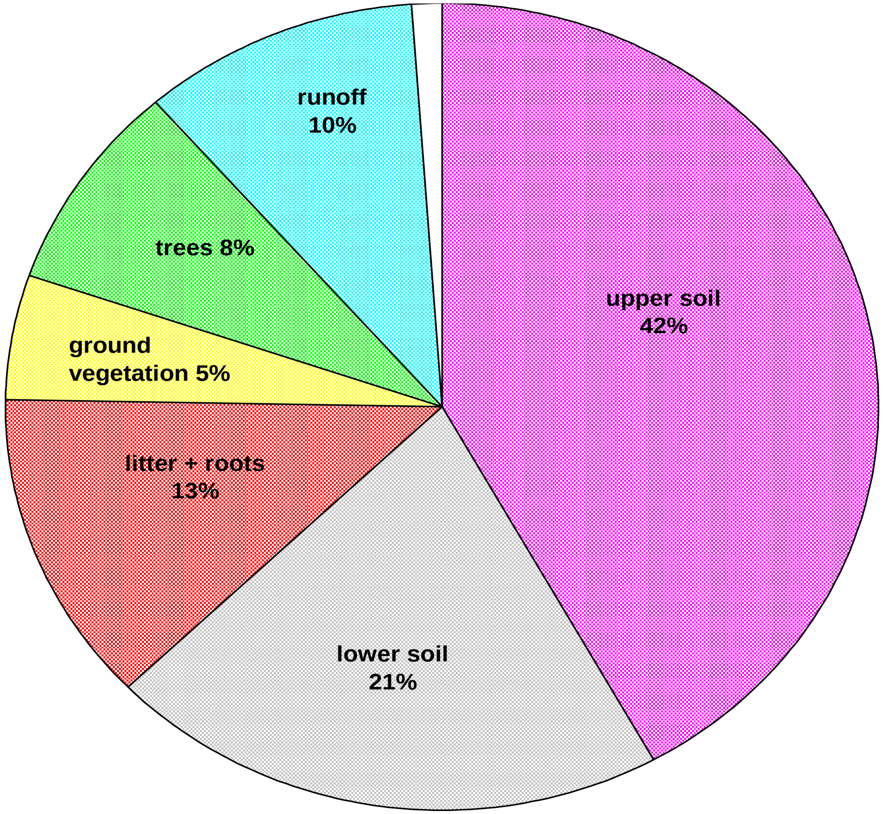


Experimental tracer application: NITREX experiments



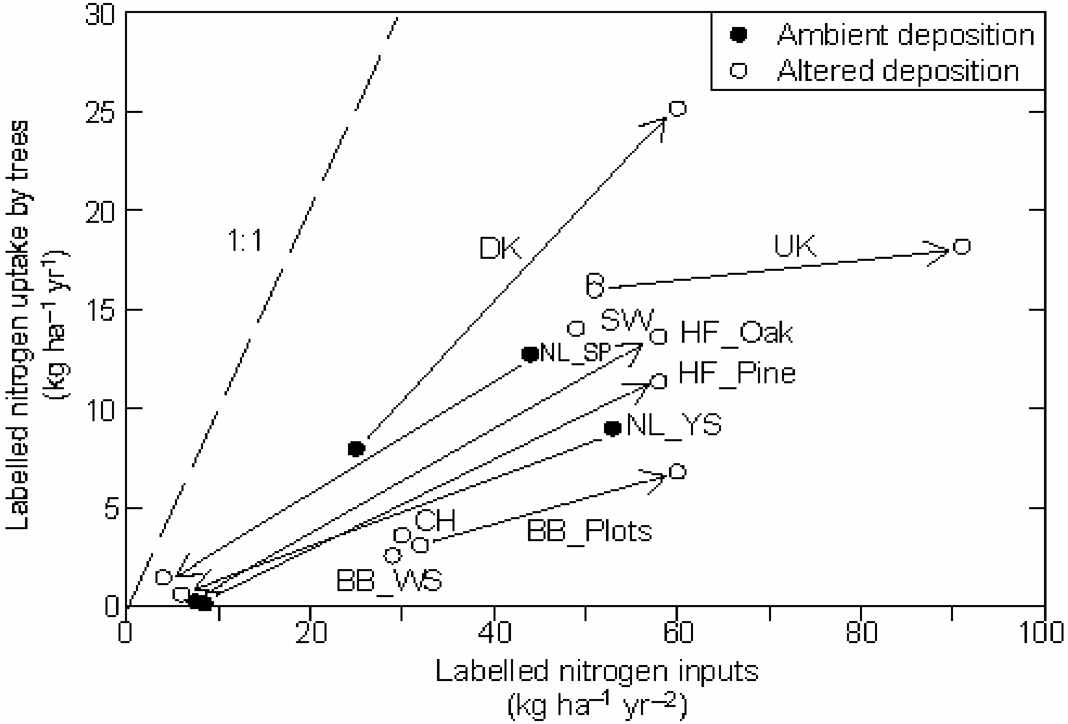
Experimental tracer application: NITREX experiments

Alptal: partitioning of ^{15}N after 1 year



Schleppi *et al.*, 1999

EU and US sites: uptake by trees



Nadelhoffer *et al.*, 1999

Isotope analysis 1: mass spectrometry

- Laboratory
- All kinds of samples: solid, liquid or gas; organic or mineral
- Costly (from 500 k€ on)
- Requires a qualified technician

Isotope analysis 2: laser absorption spectroscopy

- Also for field applications
- For liquid or gas samples, for relatively abundant elements
- E.g. $^{13}CO_2$, $H_2{}^{18}O$
- Relatively cheap (from 20 k€ on)