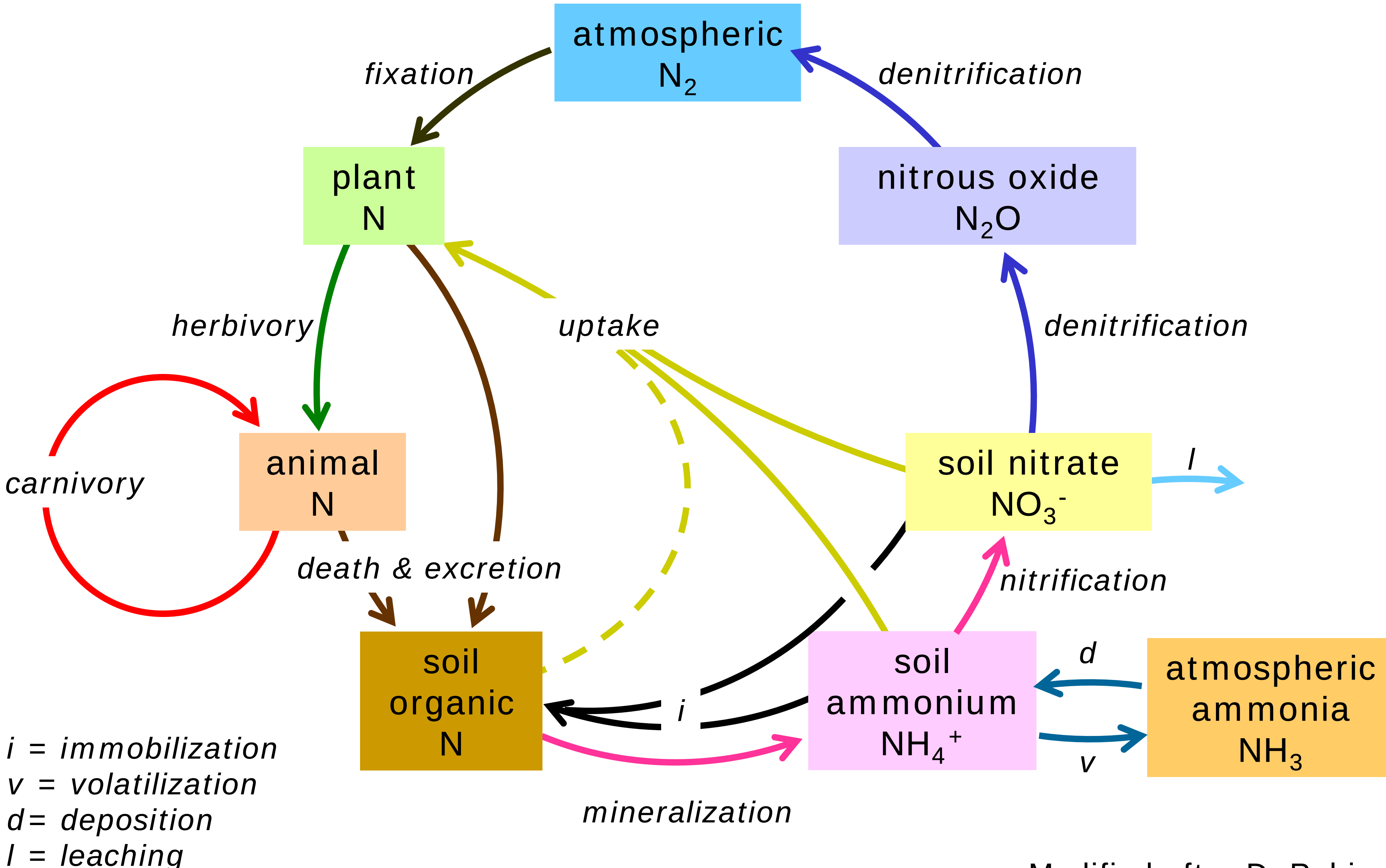
wolfgang wanek

Stable nitrogen isotopes in plant and soil processes

Natural ^{15}N abundance

Terrestrial N cycle

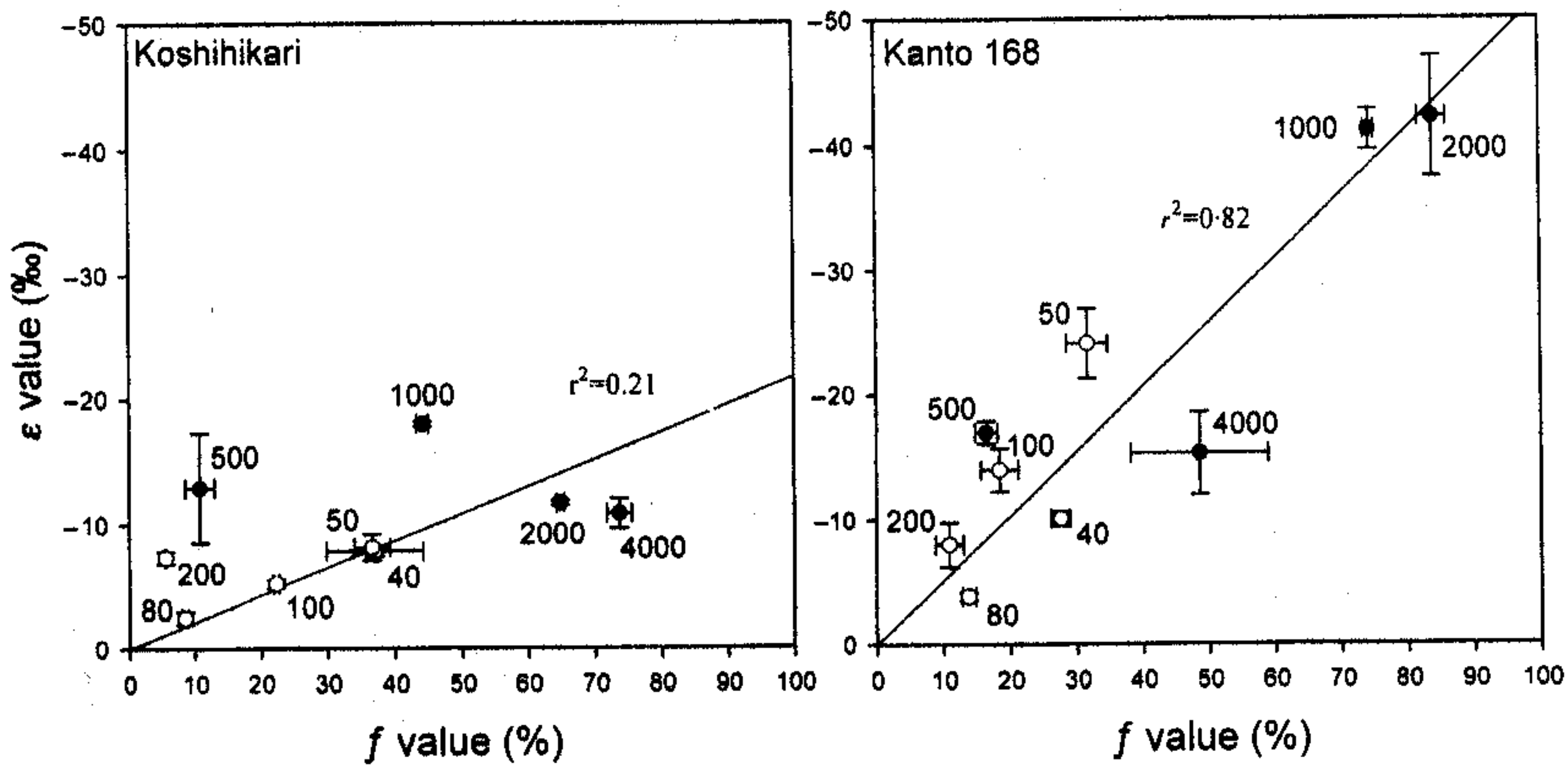


Modified after D. Robinson

Plant N processes

- Plant N uptake and ^{15}N discrimination
- Plant-mycorrhiza associations
- Symbiotic N_2 fixation (legumes)

Plant N uptake and ^{15}N discrimination



ε(-Δ) of **ammonium nutrition** by two rice cultivars
ε Range -20 to -55 ‰
f value .. % residual N left in solution
Yoneyama et al. (2001) Plant Cell Environ 24: 133

ε of **nitrate nutrition**
Koshihikari: +0.6 ± 1.8 ‰
Kanto 168: -2.5 ± 1.5 ‰

Plant N uptake and ^{15}N discrimination

Isotopic imprints in closed systems
Rayleigh distillation equation

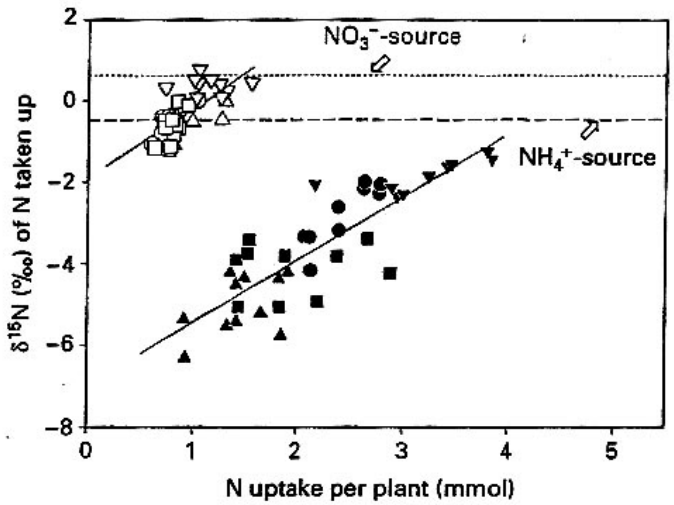
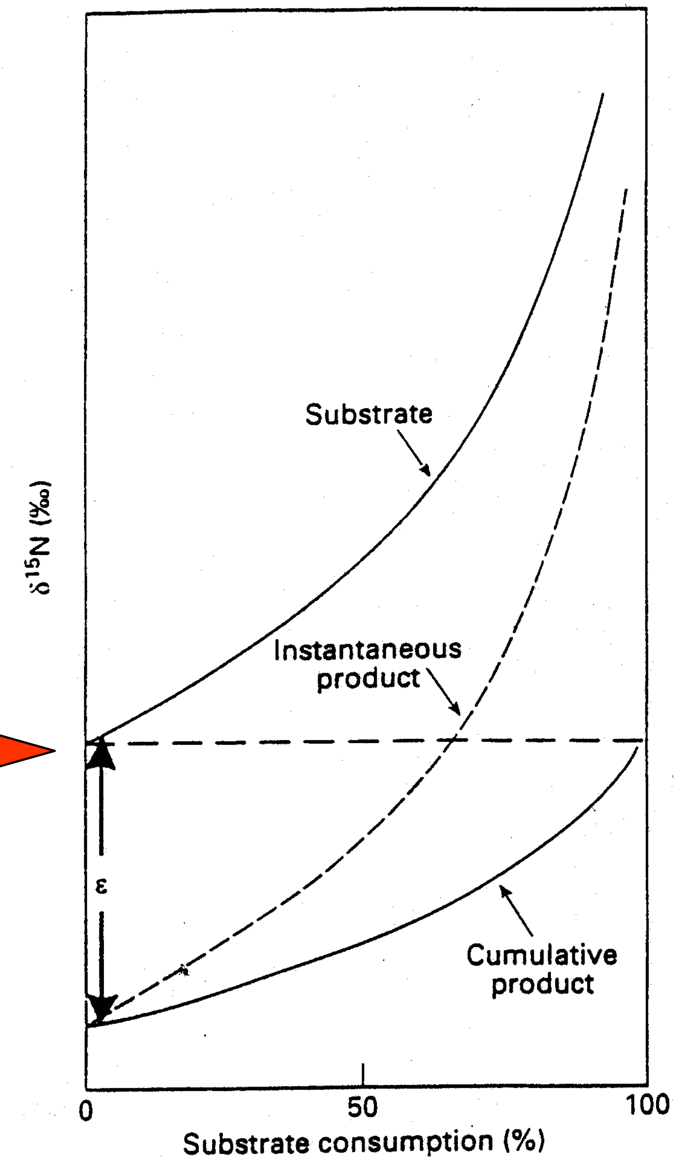


Fig. 3. Relation between the $\delta^{15}N$ of the N taken up by non-mycorrhizal and ectomycorrhizal pine seedlings and the amount of N taken up (4.6 mmol N were supplied to all treatments). There were positive correlations between the $\delta^{15}N$ of N taken up and the amount of N taken up for both NH_4^+ ($r^2 = 0.73$, $P < 0.001$) and NO_3^- ($r^2 = 0.49$, $P < 0.001$). Symbols as in Fig. 2.

Supply/
Pool size



Högberg et al. (1999) New Phytol 142: 569

Plant N uptake and ^{15}N discrimination

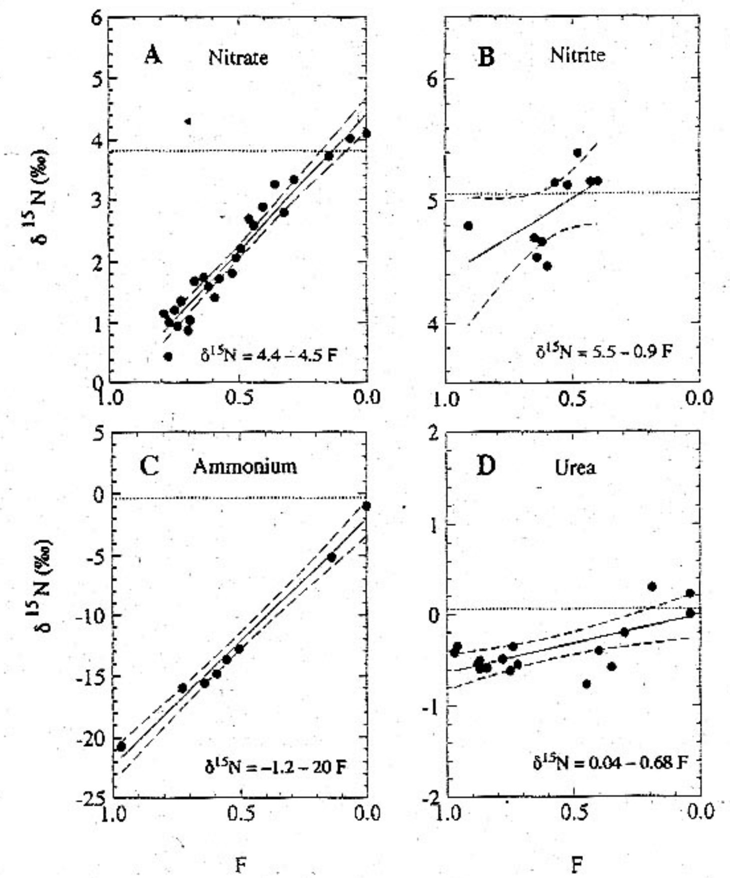


Fig. 5. Kinetic isotope fractionation during log phase for *T. pseudonana* growth on nitrate (data from Fig. 1), nitrite, ammonium, and urea (data from the first log phase, i.e. from 0 to 55 h, presented in Fig. 3). *F* is related to the fraction of unconsumed dissolved N, *f*, by the relationship $F = [-f/(1-f)]\ln f$. The solid line represents the least-squares fit of the $\delta^{15}N_{PN}$, the dashed lines are the 95% confidence intervals, and the dotted lines are the $\delta^{15}N$ of the initial N source. The regression is shown for each substrate.

Isotope discrimination during N assimilation differs between N forms

- Uptake/Influx F_{IN}
- Assimilation F_{RN} discriminates by *b*
- Efflux F_{EN}
- Net uptake $F_{NN} = F_{IN} - F_{EN}$

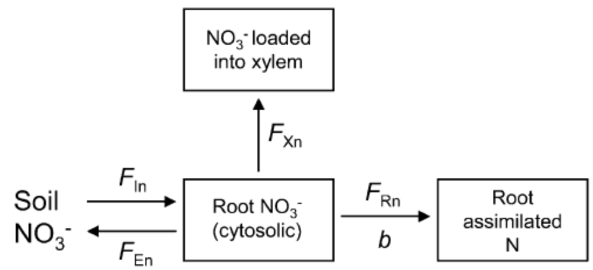


Figure 1. A simplified model of steady-state nitrate uptake, based on the conceptual model of Comstock (2001). F_{In} is the influx of nitrate from the soil solution into root cells; F_{En} is the efflux of nitrate from root cells back to the soil solution; F_{Rn} is the assimilation flux of nitrate into organic molecules within root cells; and F_{Xn} is the flux of nitrate from root cells into the xylem. Nitrate loaded into the xylem is carried to the leaf in the transpiration stream, where it can also be assimilated into organic molecules. Because nitrate is not exported from leaves in the phloem, the flux of nitrate into the xylem in the root is equal to the assimilation flux in the shoot in the steady state. The discrimination against ^{15}N during nitrate reduction in both the root and the shoot is defined as *b*, which is a constant. F_{In}, F_{En}, and F_{Xn} are assumed to proceed without discrimination against ^{15}N.

$$\delta_{plant} = \delta_{NO3} - F_{RN}/F_{NN} * (1 - F_{NN}/F_{IN}) * b$$

Cernusak et al. (2009) Plant Physiology 151: 1667

Effect of mycorrhiza on plant ^{15}N discrimination

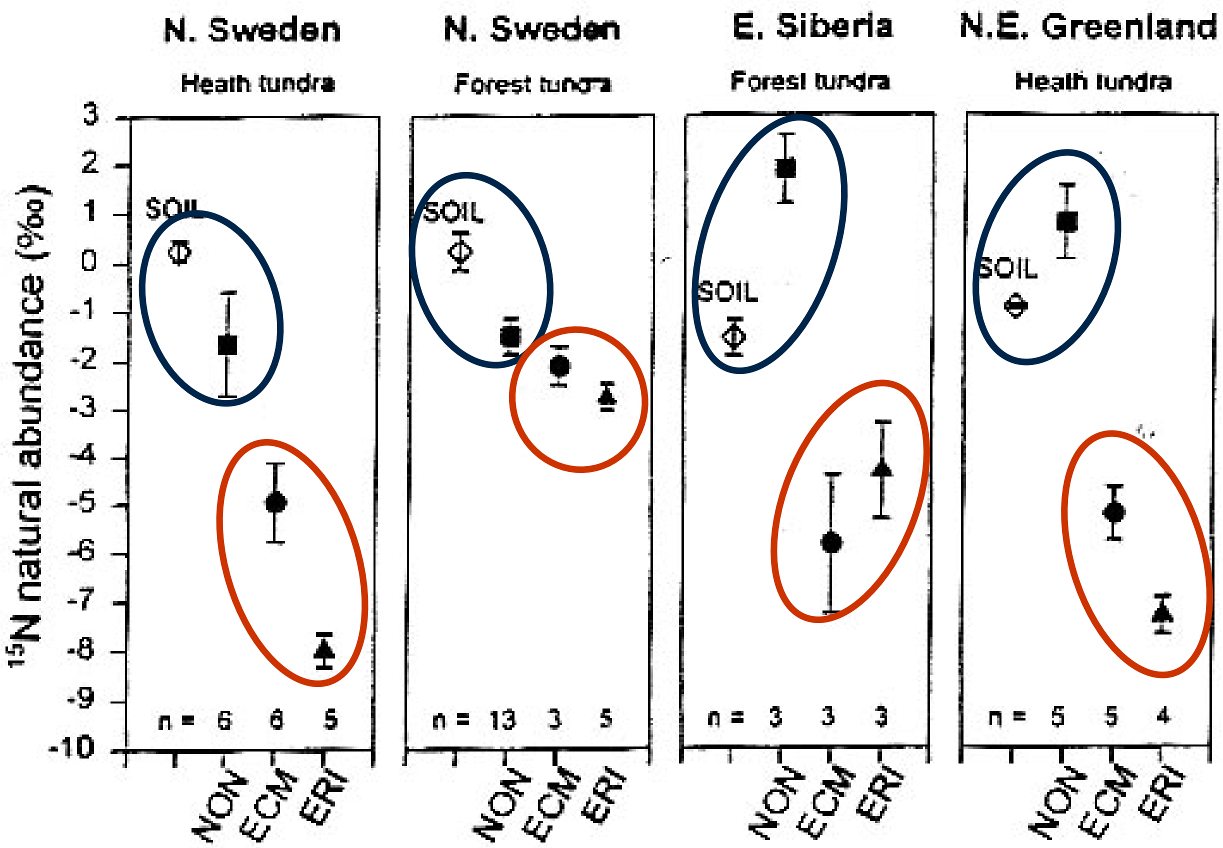
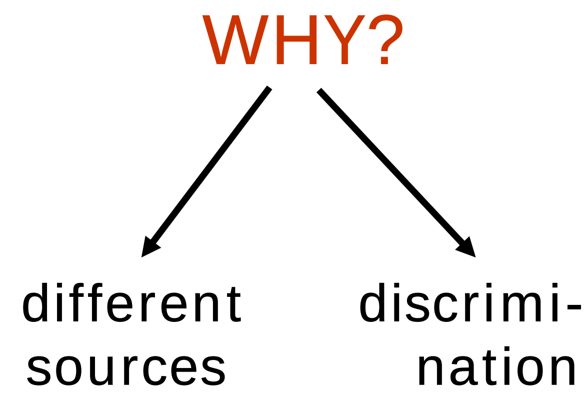


Fig. 2 Mean $\delta^{15}N$ ($\pm$SE) of plant species without mycorrhiza (*NON*), with ectomycorrhizal (*ECM*) fungi or with ericoid mycorrhizal (*ERI*) fungi at the four heath and forest tundra sites in Fig. 1. The means within each functional group and site are based on the means of the species presented in Fig. 1; *n* is the number of replicates (plant species)



Michelsen et al. (1998) Oecologia 115: 406

N transfer in plant-myc associations

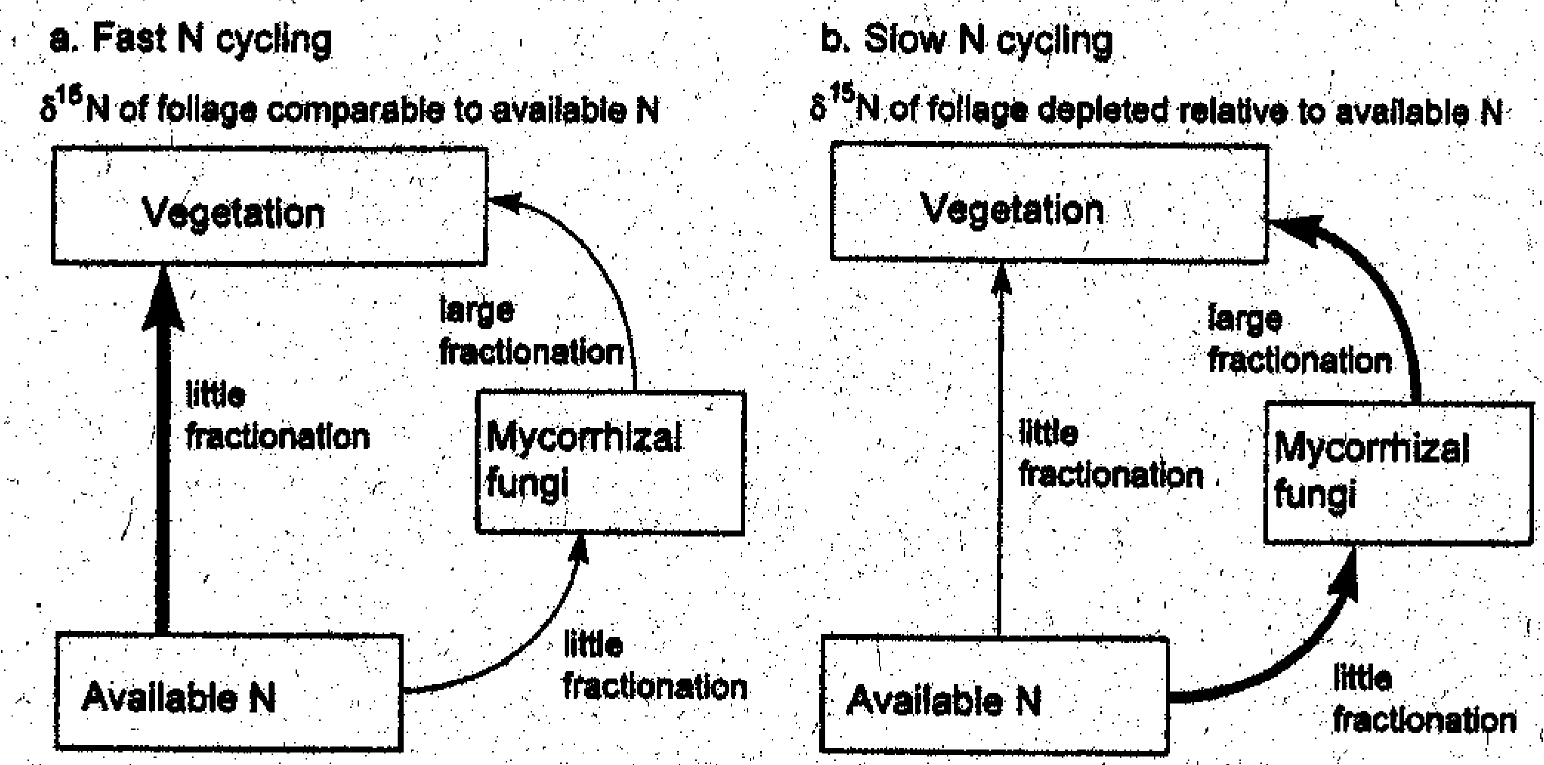
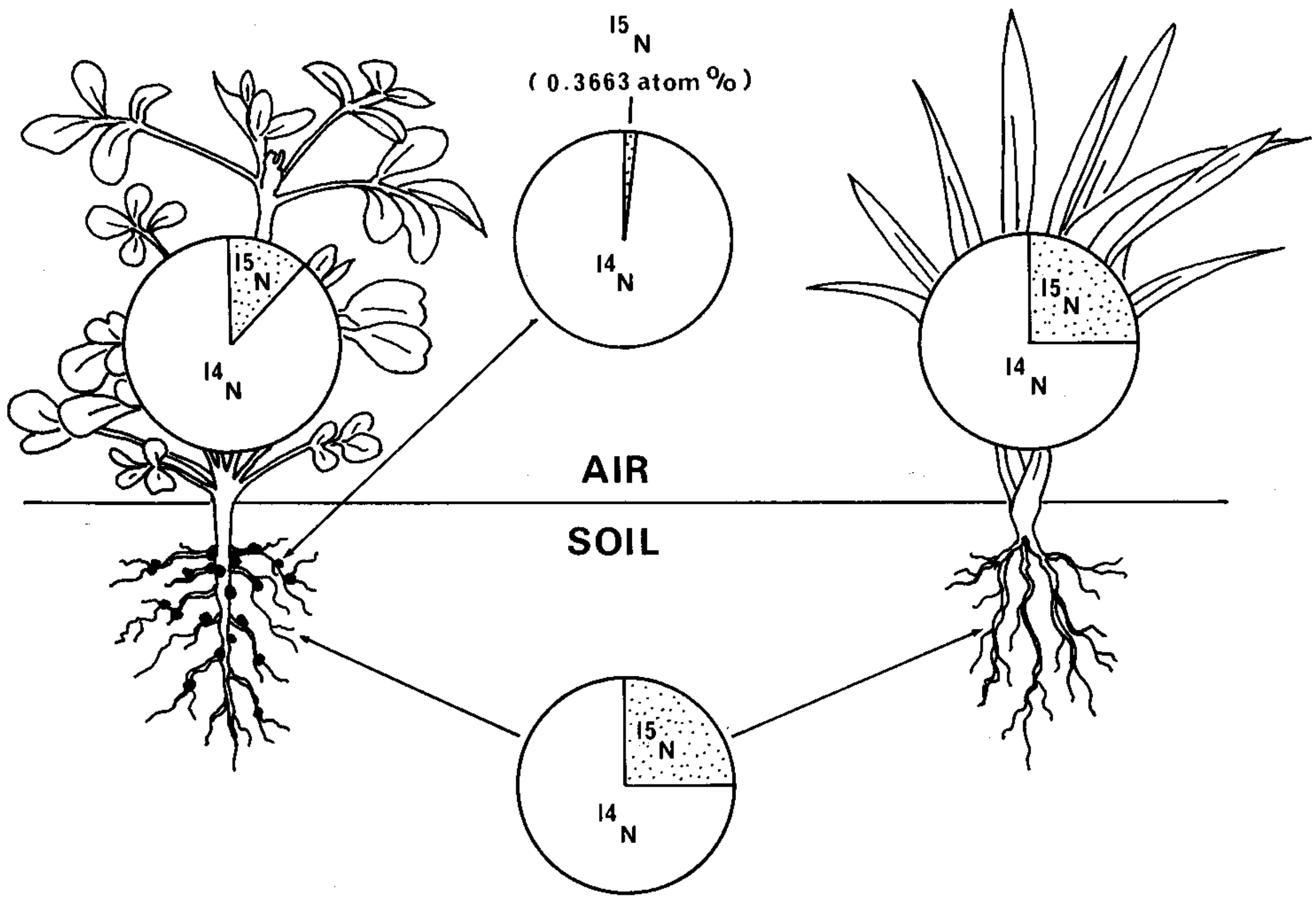


Fig. 5 Schematic diagram of hypothesized interactions among vegetation, soil available N, and mycorrhizal fungi under conditions of rapid N cycling (**a**), or slow N cycling (**b**)

Hobbie et al. (2000) Oecologia 122: 273

Natural ^{15}N method for estimating the proportion of N derived from N_2 fixation

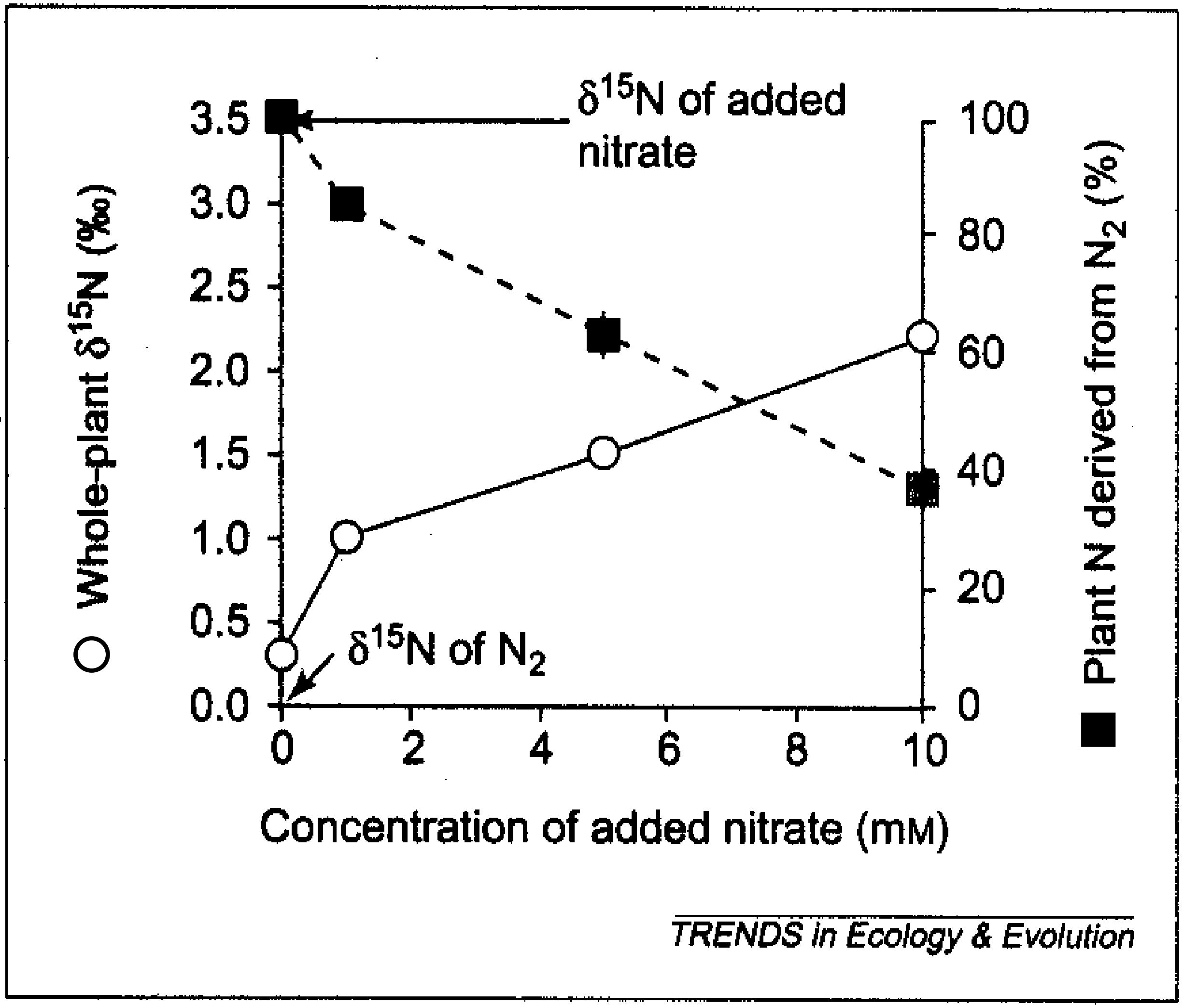


$$\%Ndfa = 100 * (\delta^{15}N_{ref} - \delta^{15}N_{leg}) / (\delta^{15}N_{ref} - B)$$

B-value: $\delta^{15}N$ of legume totally independent on soil N (-1.0 to -2.5 ‰)

Peoples et al. (1989) ACIAR Series

Symbiotic N_2 fixation (legumes) and N availability



Unkovich et al. (2000) Aust J Plant Physiol 27: 921

Fig. 1. An example of the use of natural ^{15}N abundances ($\delta^{15}N$) to estimate the proportion of plant N derived from the atmosphere by symbiotic N_2 fixation[9]. The tree legume *Chamaecytisus proliferus* was grown in sand containing different amounts of added NO_3^- with a $\delta^{15}N$ value of +3.5‰. $\delta^{15}N$ of N_2 is, by definition (Box 1), 0‰. Whole-plant $\delta^{15}N$ values (circles) varied within these limits, depending on how much N was derived from N_2 and NO_3^-, becoming more ^{15}N enriched as the availability of source NO_3^- increased. From these data, the proportion of plant N derived from N_2 (squares) was estimated using a mixing model (Box 2).

Soil and ecosystem N dynamics

- Soil ^{15}N enrichment (bulk and inorganic N)
- Nitrification, Denitrification
- Ecosystem N losses and global patterns

Isotopic signatures of bulk soil N

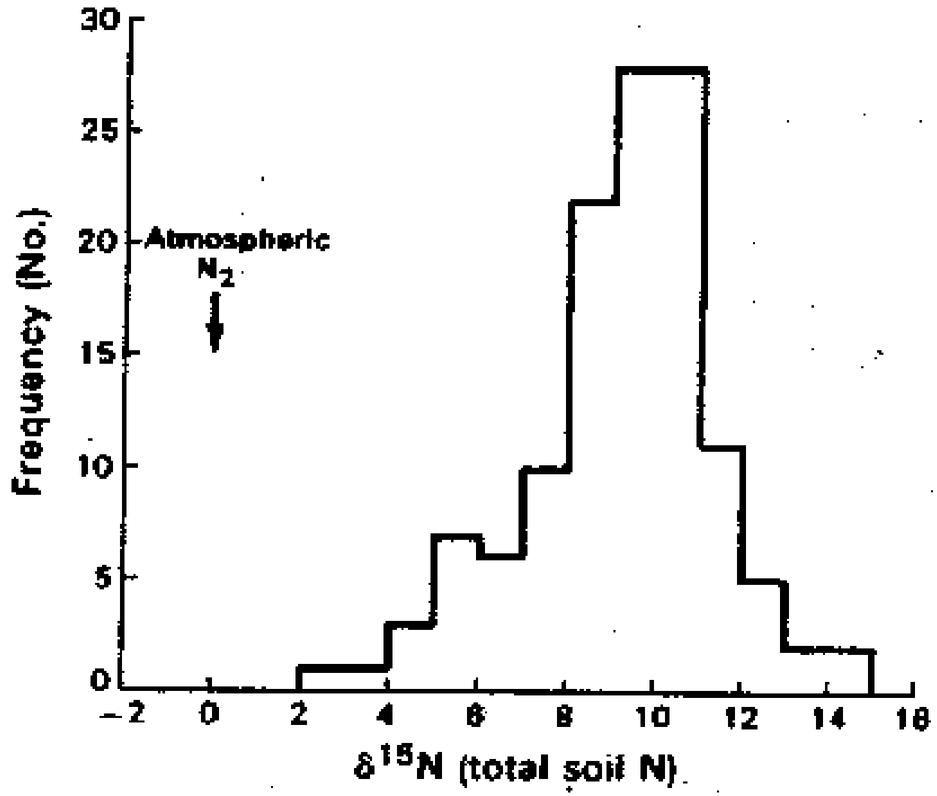
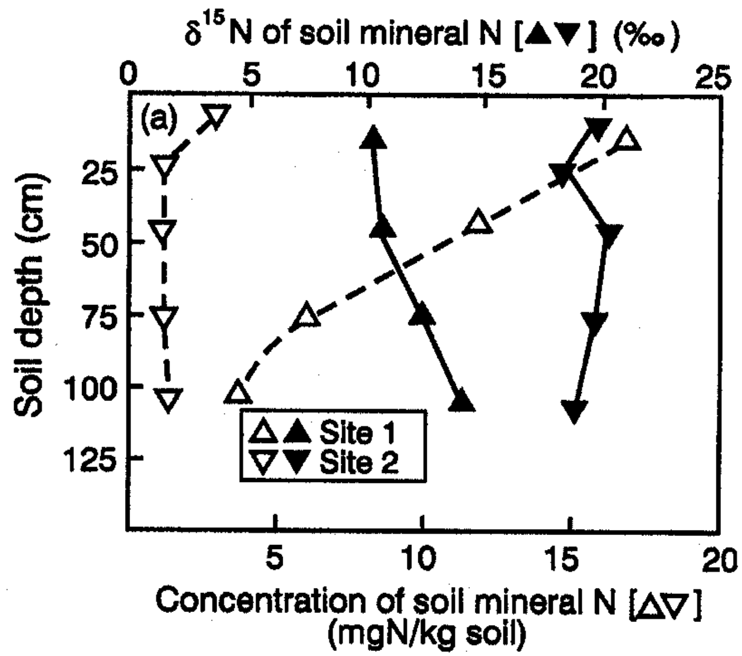


Fig. 1. Frequency distribution of $\delta^{15}N$ values of total soil N in 124 surface soils from 20 States of the U.S.A. Mean $\delta^{15}N$ was 9·92. Samples were collected near the soil surface. Modified from Shearer *et al*. (1978).

Bulk soil ^{15}N enriched compared to atm. N_2

$\delta^{15}N$ of mineral N across soil profiles



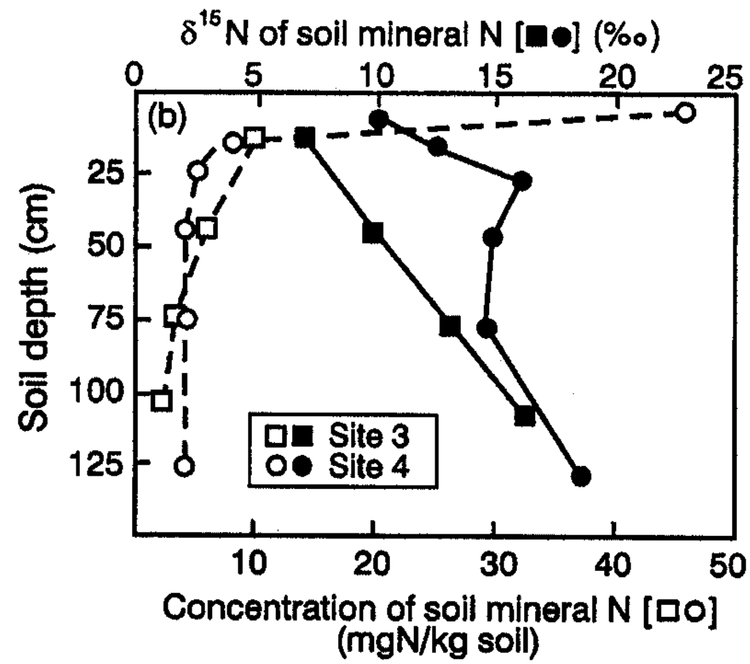


Figure 3. Changes in concentration and ^{15}N abundance of mineral N (NH_4^++NO_3^-) in the profile of different cropping and perennial pasture systems where the $\delta^{15}N$ of soil mineral N is either (A) relatively similar or (B) changes down the profile (data from Peoples et al., 1995b).

Soil ^{15}N enrichment due to cumulative losses

Concentration and $\delta^{15}N$ of mineral N in cropping and perennial pasture systems in New Zealand
Boddey et al. (2001) Nutr Cycl Agroecosystems 57: 235

Soil N processes and ^{15}N discrimination

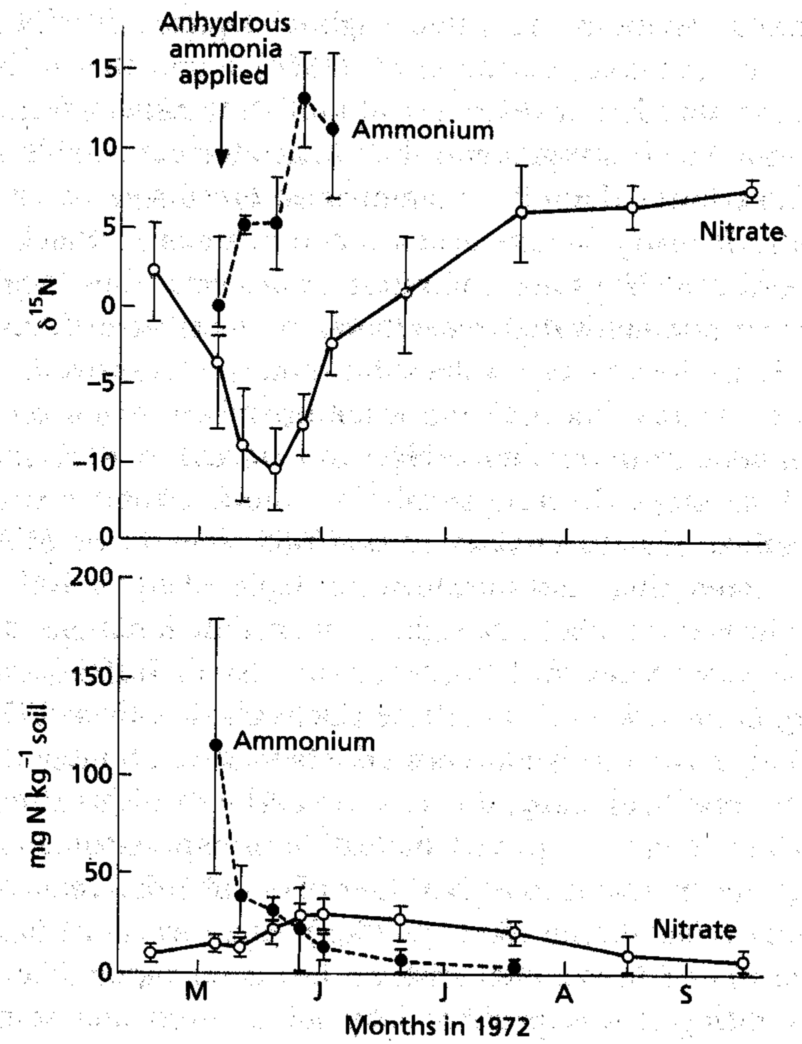


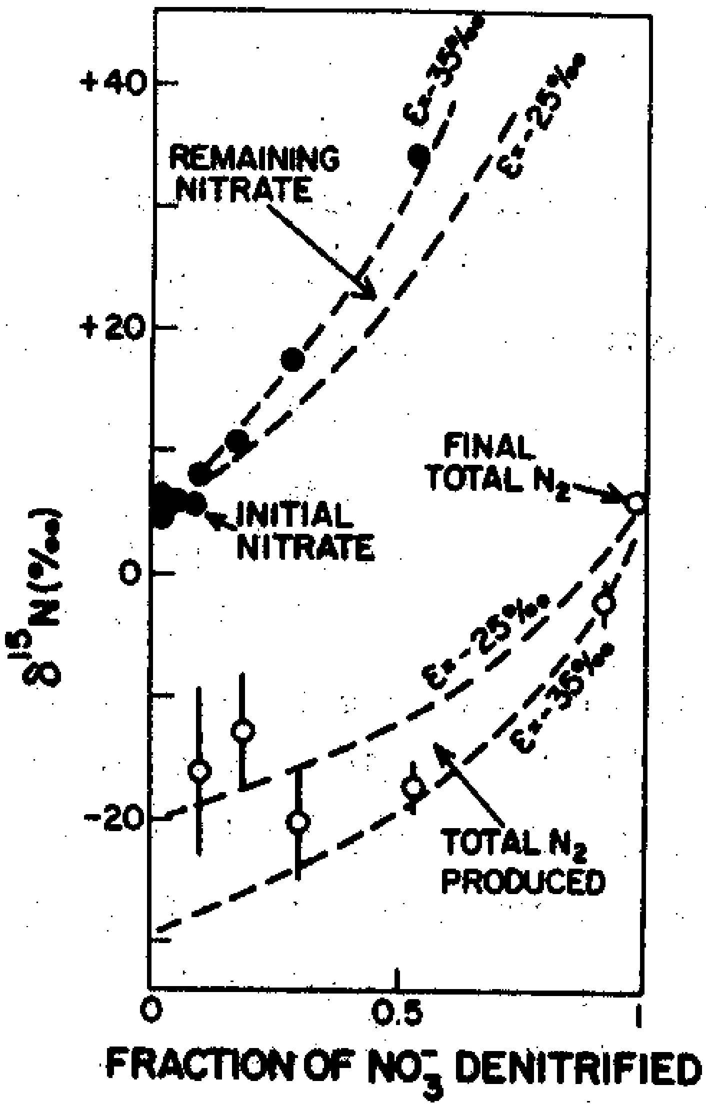
Fig. 2.3 The conversion of NH_4^+ to NO_3^- and changes in the $\delta^{15}N$ values of these to nitrog forms following application of anhydrous NH_3 fertilizer to an agricultural field. (From Feigin *et al*., 1974b.)

Microbial NITRIFICATION (ammonium oxidation to nitrate)

(Δ ~ 15-50‰)

Feigin et al. (1974)

Soil N processes and ^{15}N discrimination



Microbial DENITRIFICATION (dissimilatory reduction of nitrate to nitrite, NO, N_2O and N_2)

(Δ ~ 0 - 35‰)

Mariotti et al. (1981) Plant Soil 62: 413

Ecosystem N losses and foliar $\delta^{15}N$

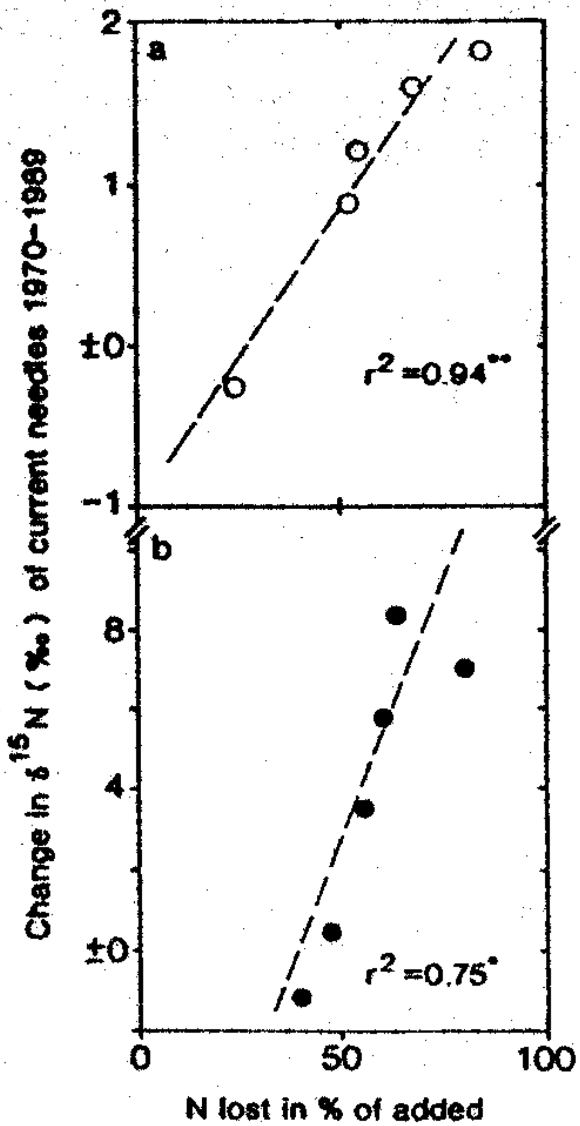


Fig. 1. The relation between the fractional loss of added N from plots fertilized with N or NPK and the change in ^{15}N abundence of current needles of Scots pine during the experiment at Norrliden 1970–1989. **a**, plots fertilized with NH_4NO_3; **b**, plots fertilized with urea (cf. Table 1). Each data point represents the mean for 2–3 plots.

Högberg & Johannisson (1993) Plant Soil 157: 147

Rates of soil N cycling and foliar $\delta^{15}N$

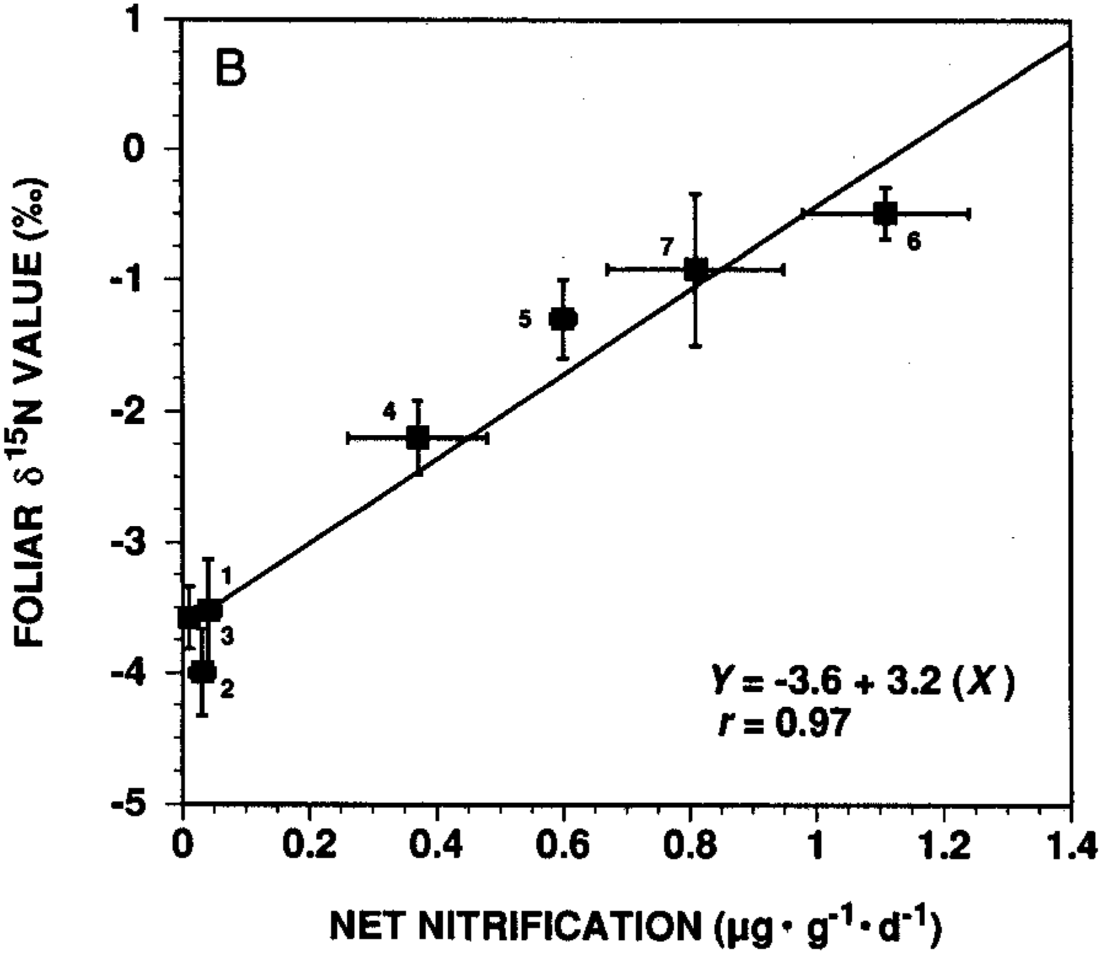


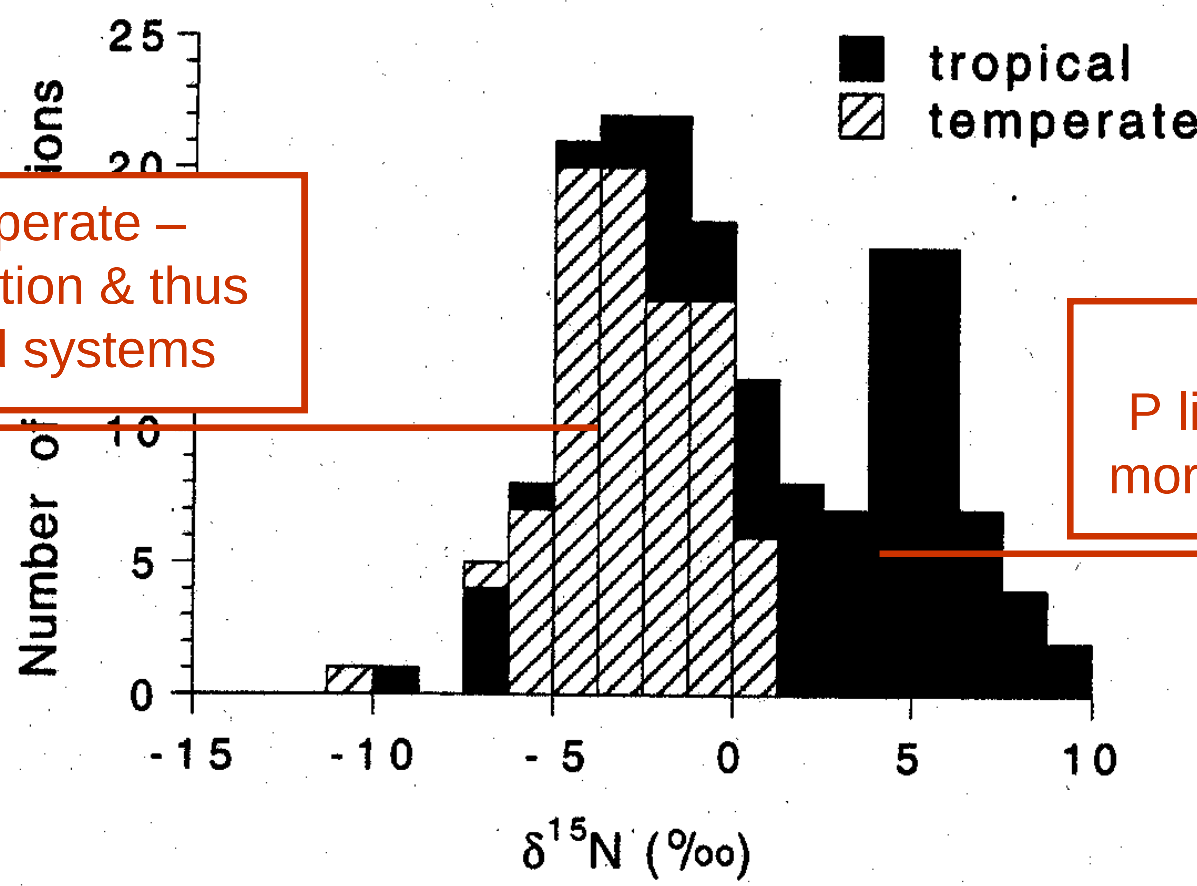
FIG. 11. Relationship between mean enrichment factors ($\delta^{15}N_{leaf} - \delta^{15}N_{soil}$) (A) or mean foliar ^{15}N abundance (B) in deciduous trees and net nitrification potential per unit of soil dry mass in laboratory incubations of surface mineral soil. Data are means ± 1 SE. Numbers next to each point designate the following data sets: red maple and dogwood trees from (1) SW-facing slopes, (2) ridges, (3) NE-facing slopes, and (5) valley bottoms in the summer of 1989 on Walker Branch Watershed; mixed deciduous tree species from (4) ridge and (6) valley-bottom sampling sites on Walker Branch Watershed in the summer of 1991; and (7) sycamore and sweet gum trees from a plantation at the Oak Ridge National Laboratory 0800 Area.

Higher net nitrification = higher N losses by leaching or denitrification

The higher the N losses the higher the residual inorg. N and plant $\delta^{15}N$ values

Garten (1993) Ecology 74: 2098

Comparison of foliar $\delta^{15}N$ between temperate and tropical forests



Temperate –
N limitation & thus
closed systems

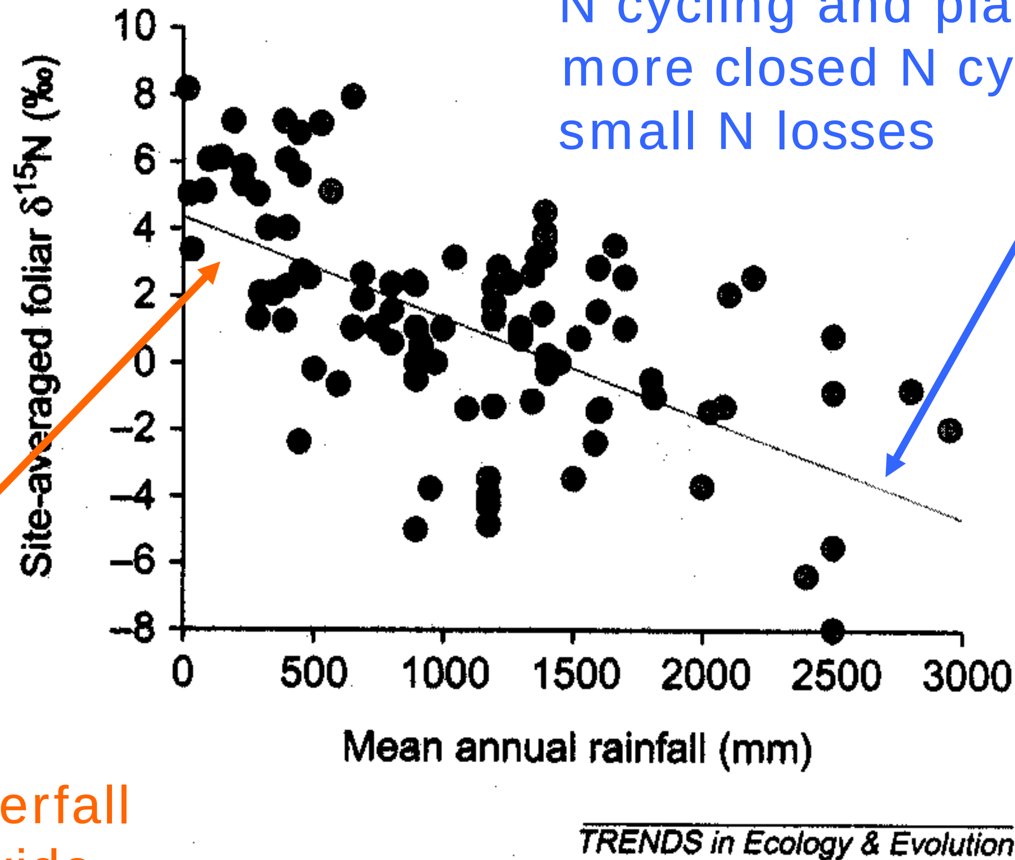
Tropical –
P limitation & thus
more open systems

Figure 1. Histogram of $\delta^{15}N$ (‰) for tree leaves collected in tropical and temperate forests. Solid bars are tropical sites and hatched bars are temperate sites. (b) Plot of $\delta^{15}N$ (‰) for tree leaves collected in tropical and temperate forests. Error bars represent one standard-deviation.

Martinelli et al. (1999) Biogeochemistry 46: 45

Ecosystem N cycling and foliar $\delta^{15}N$: influence of mean annual precipitation

Fig. 5. Correlation between foliar $\delta^{15}N$ (averaged across the plant taxa at each site) and the mean annual rainfall at those sites; data collated from numerous sources[15]. The regression foliar $\delta^{15}N = 4.49 - 0.003$. Rainfall is significant at $P<0.000$, $r=-0.59$, $n=97$.



Perhumid forests: year-round N cycling and plant growth, more closed N cycling → small N losses

Strong seasonality: Litterfall and decomposition provide pulses of N when vegetation is inactive → large N losses, open N cycle

Handley et al. (1999) Aust J Plant Physiol 26: 185

Comparison of foliar δ^{15}N between temperate and tropical forests

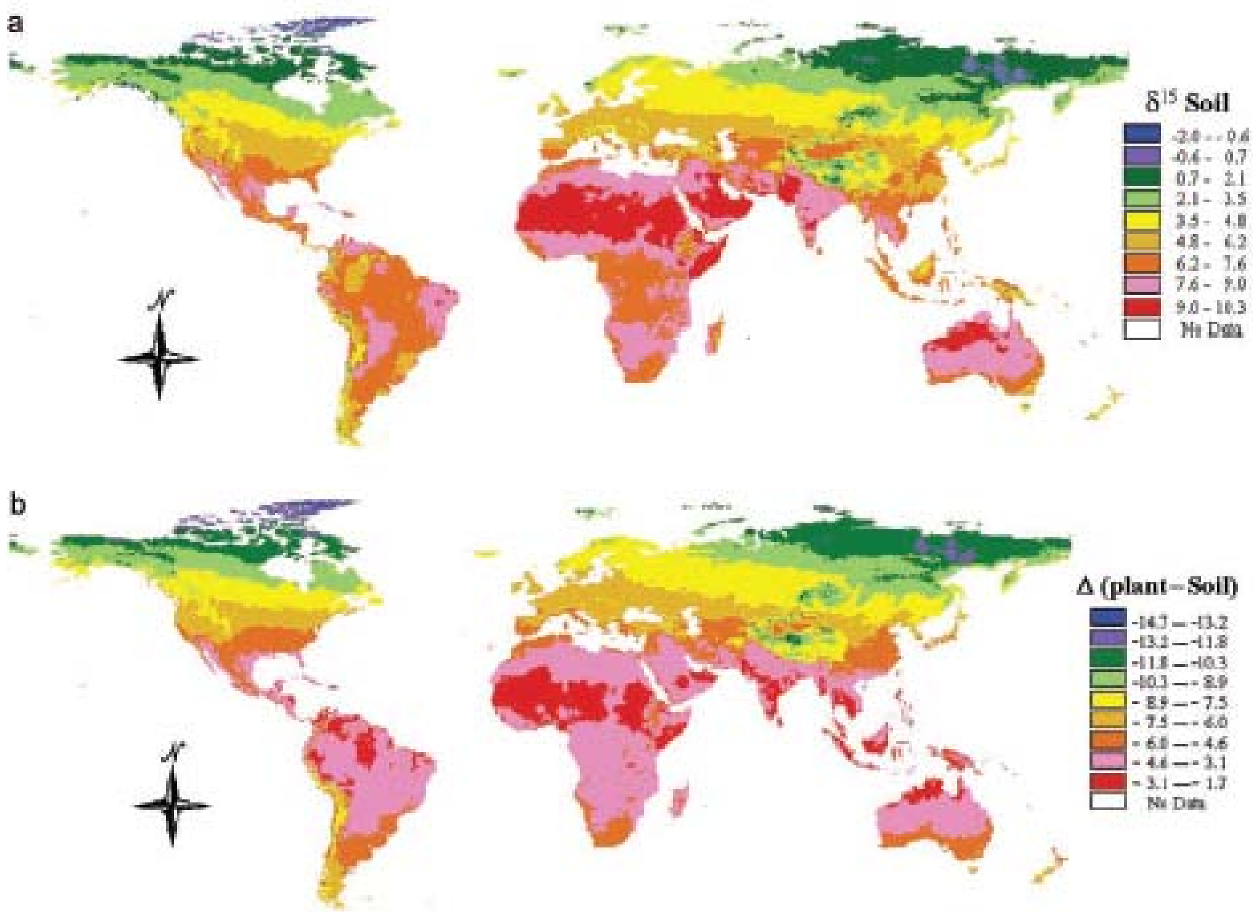


Figure 2. (a) Estimated geographical distribution of soil δ^{15}N values to 50 cm and (b) estimated geographical trends in Δδ^{15}N$_{plant-soil}$. Global mean annual temperature and precipitation (0.5 × 0.5 degree grids) data are obtained from *Willmott and Matsuura* [2000].

- Low ^{15}N enrichment in Northern ecosystems
- High ^{15}N enrichment in tropical ecosystems

+ DIN and gaseous N (strongly ^{15}N depleted) in tropics
+ low losses from northern ecosystems (pref. ^{15}N enriched DON)

Amundson et al. (2003) Glob Biogeochem Cycles 17: 1031