Nitrogen and Soil

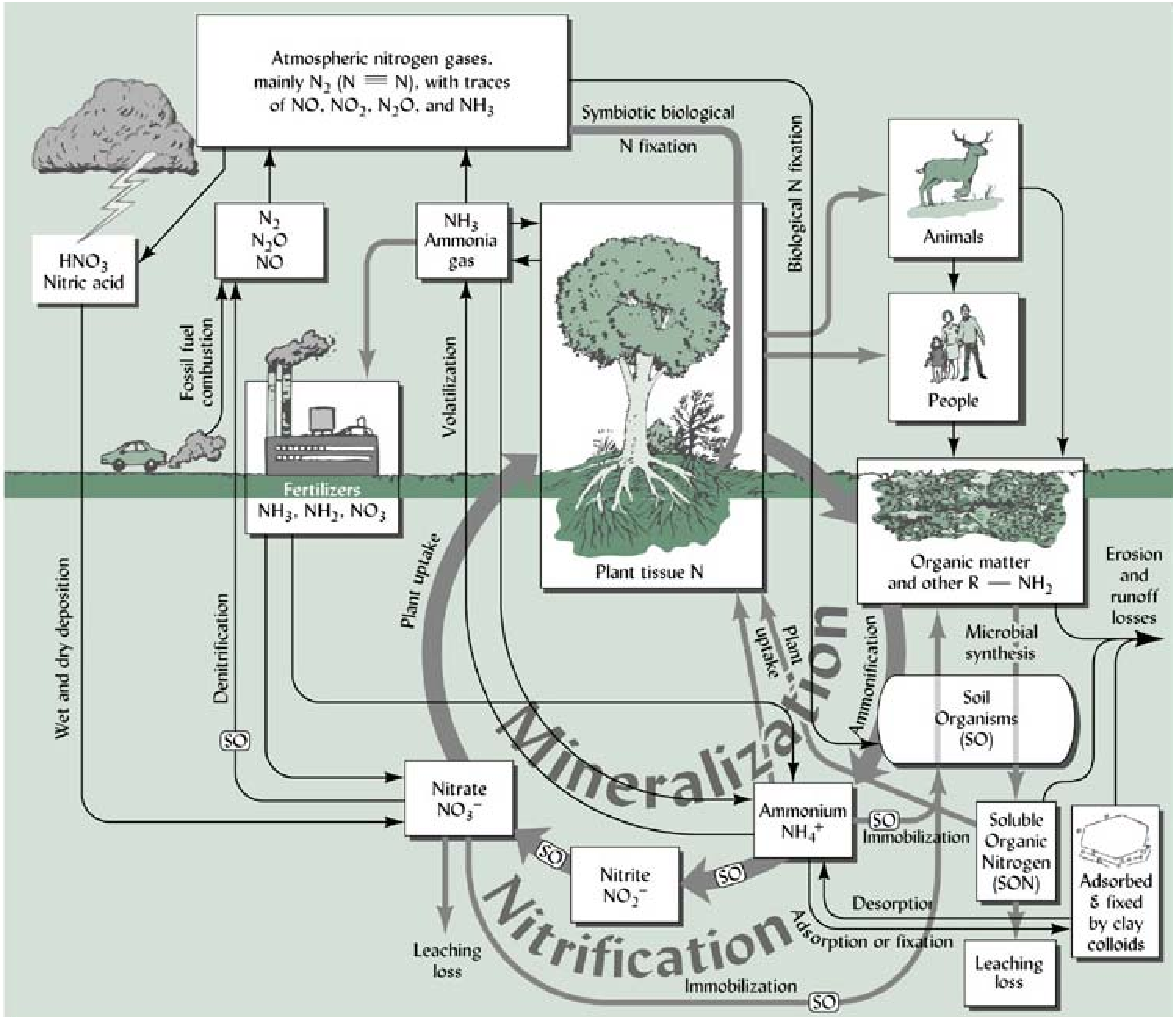


Figure 13.2

The Nitrogen Cycle

Three questions to think about

- What are the pools
- What are the sources and losses
- What are the fluxes

Then think about what controls these…

NB ~ flux rates and pools are controlled by edaphic environmental conditions, while N sources are often global in nature!

1. Where is it?

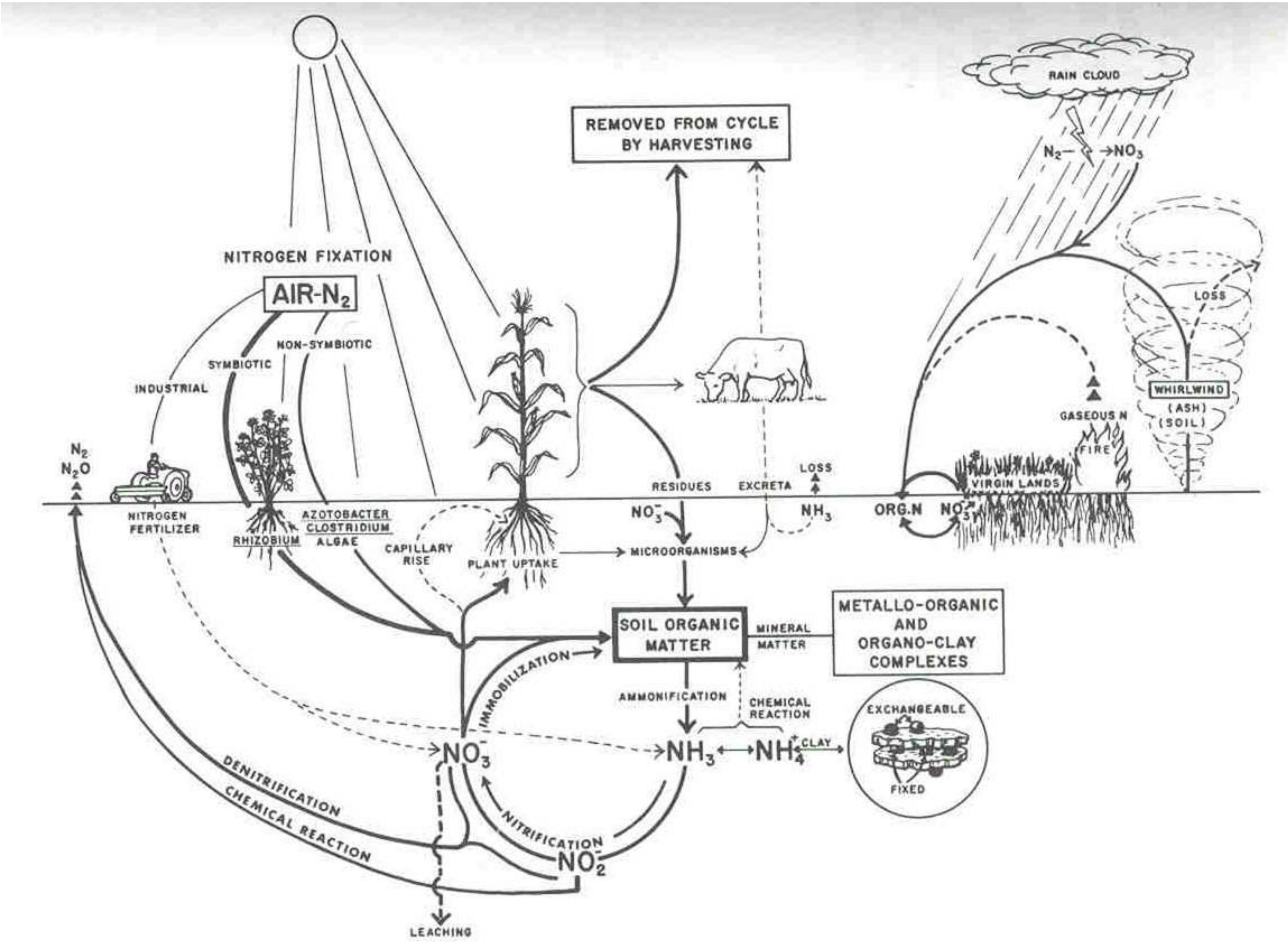
Table 4.1

Inventory of N in the Four Spheres of the Earth[a]

Sphere	N Content, × 10^{16} kg
Lithosphere	16,360
Igneous rocks	
Of the crust	100
Of the mantle	16,200
Core of the earth	13
Sediments (fossil N)	35–55
Coal	0.007
Sea-bottom organic compounds	0.054
Terrestrial soils	
Organic matter	0.022
Clay-fixed NH_4	0.002
Atmosphere	386
Hydrosphere	
Dissolved N_2	2.19
Combined N	0.11
Biosphere	0.028–0.065

[a] Most estimated are from Burns and Hardy[3] and Söderlund and Svensson.[9] The values for terrestrial soils are from Stevenson.[1]

2. So where is the Biosphere and Soil N coming from and where is it going?



Source of N into pedosphere (soil) and biosphere

1. Biological N fixation – symbiotic and non-symbiotic
2. Fertilizer –

    Industrial N Fixation and

    Emissions ~ 0.78 to 22 kg / ha
3. Lightning
4. Off site OM additions
5. Dust – particulate matter

Estimated Average Rates of Biological N_2 Fixation for Specific Organisms and Associations[a]

Organism or System	N_2 Fixed, kg/ha · year
Blue-green algae	25
Free-living microorganisms	
Azotobacter	0.3
Clostridium pasteurianum	0.1–0.5
Plant–algal associations	
Gunnera	12–21
Azollas	313
Lichens	39–84
Legumes	
Soybeans (*Glycine max* L. Merr.)	57–94
Cowpeas (*Vigna*, *Lespedeza*, *Phaseolus*, and others)	84
Clover (*Trifolium hybridium* L.)	104–160
Alfalfa (*Medicago sativa* L.)	128–600
Lupines (*Lupinus* sp.)	150–169
Nodulated nonlegumes	
Alnus	40–300
Hippophae	2–179
Ceanothus	60
Coriaria	150

[a] From Evans and Barber.[16]

World fertilizer use

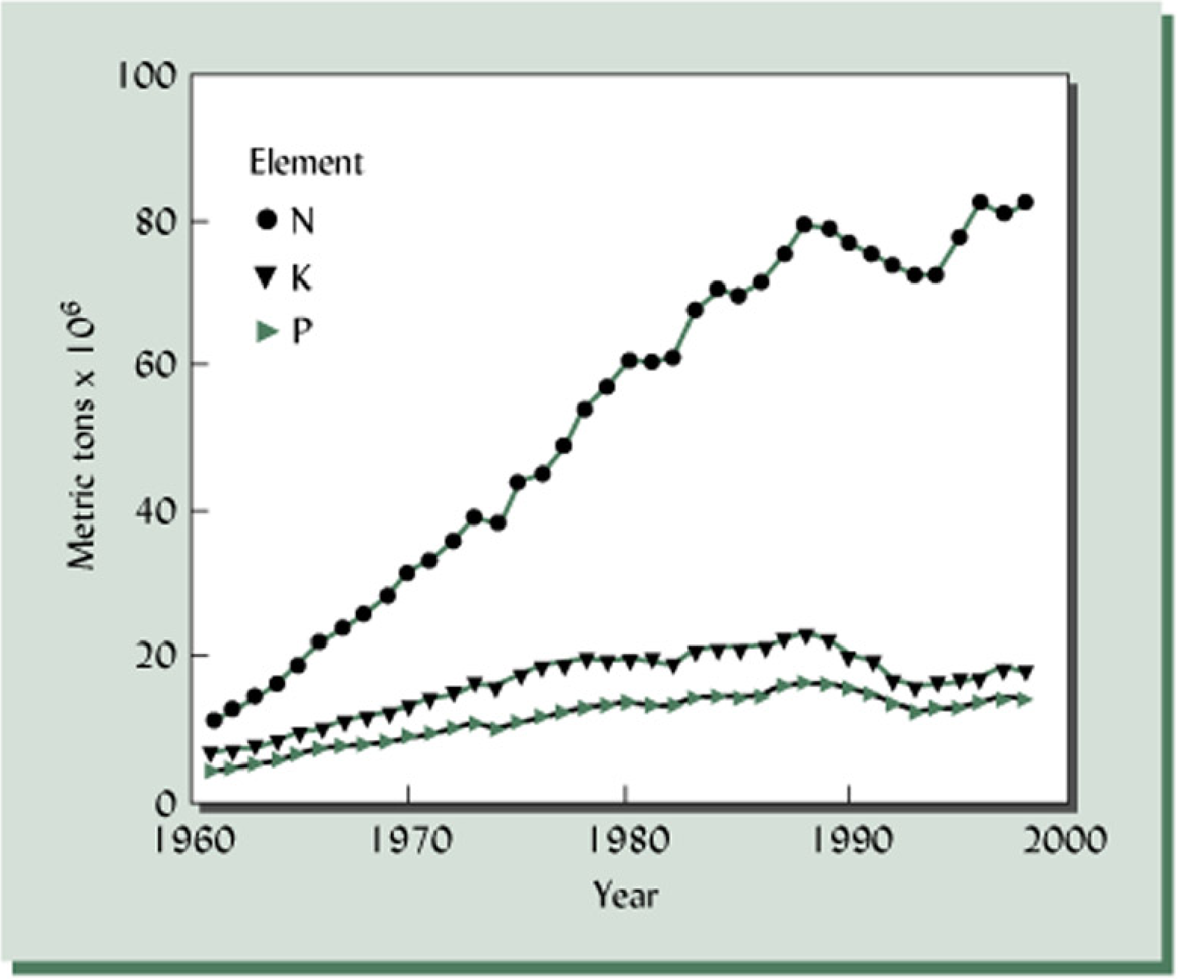


Table 4.14

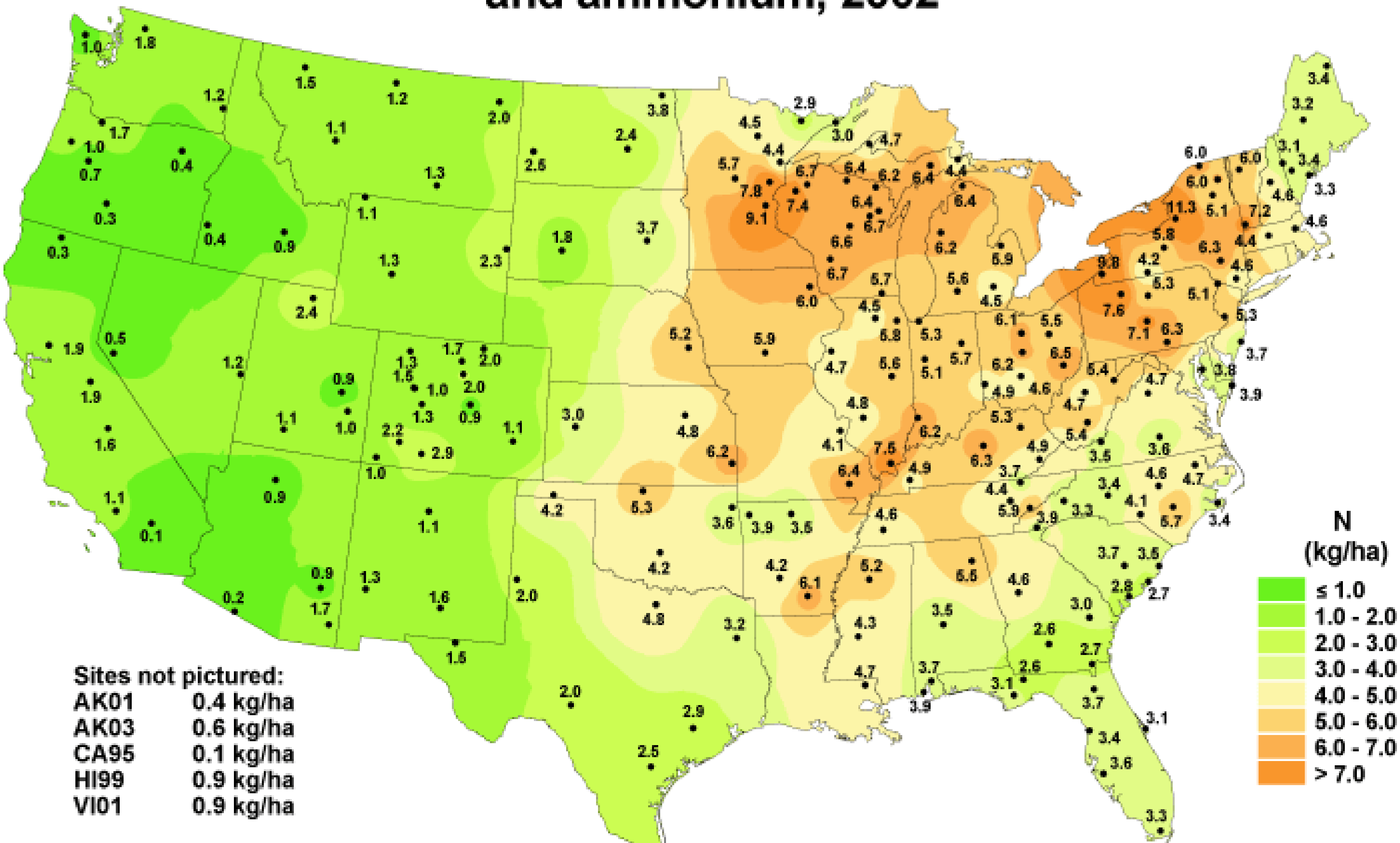
Inputs and Outputs of N in Harvested Croplands and Total Land Area in the United States[a]

Estimated Fluxes	1930	1947	1967	1970
	10^9 kg of N per year for croplands			10^9 kg of N per year for total area
Inputs of N				
Fertilizer N	0.3	0.7	6.8	7.5
Symbiotic N_2 fixation	1.5	1.7	2.0	3.6
Nonsymbiotic N_2 fixation	1.0	1.0	1.0	1.2
Barnyard manure	0.9	1.3	1.0	–
Rainfall	0.8	1.0	1.5	5.6
Irrigation	<0.1	–	–	–
Roots and unharvested portions	1.0	1.5	2.5	–
Total inputs	5.5	6.2	14.8	17.9[b]
Outputs of N				
Harvested crops	4.2	6.5	9.5	16.8
Erosion	4.5	4.0	3.0	–
Leaching of soil N	3.7	3.0	2.0	–
Denitrification	–	?	?	8.9
Volatilization	–	–	–	5.6
Total outputs	12.4	13.5	14.5	19.5

[a] From Hauck and Tanji[5] as tabulated from data of Lipman and Corybeare,[103] and Stanford et al.[104]

[b] An additional 3.1×10^9 kg was assumed to be derived from the soil organic matter, giving a total of 21.0×10^9 kg.

Inorganic nitrogen wet deposition from nitrate and ammonium, 2002



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

3. What are the fluxes?

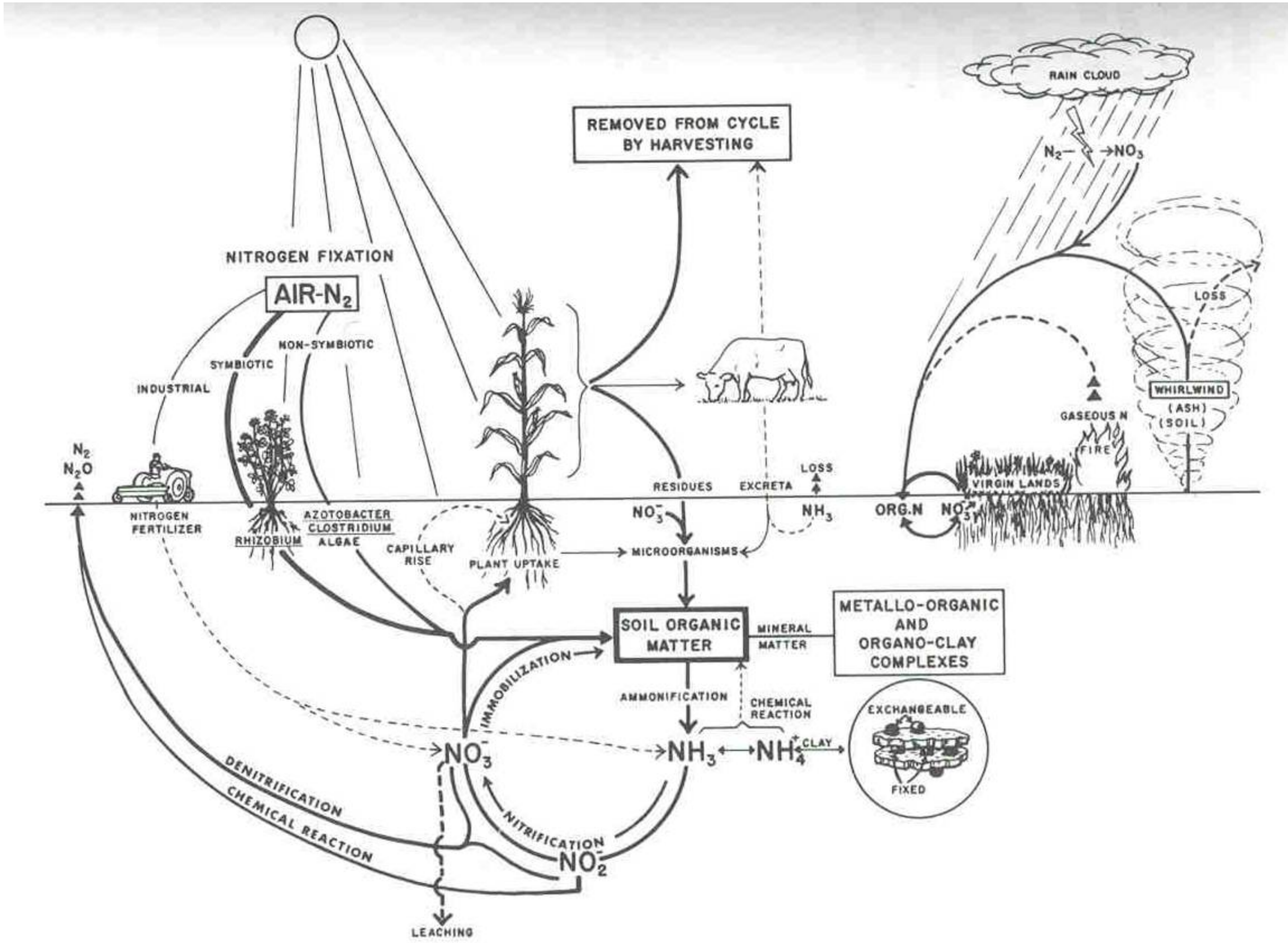
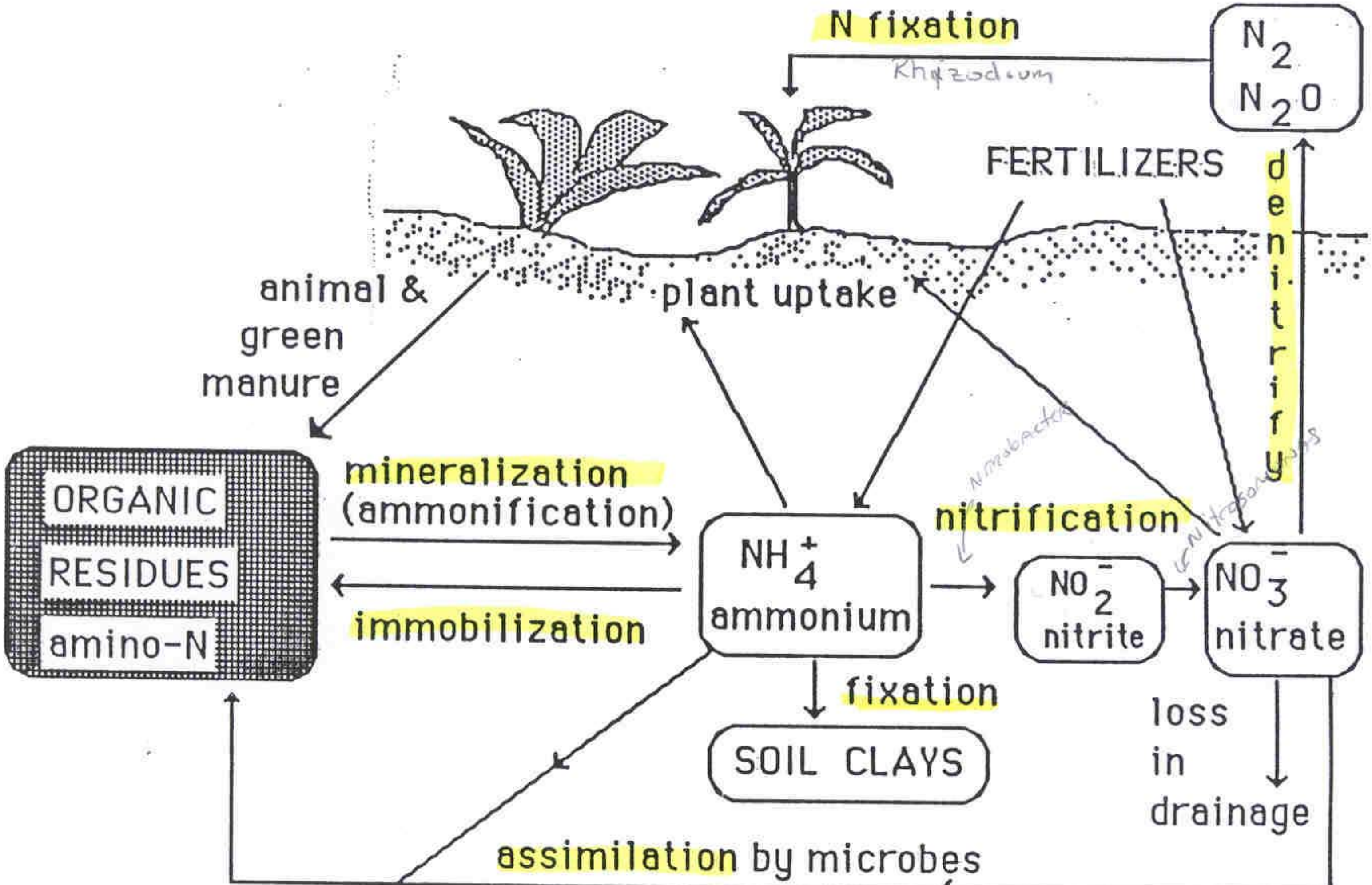
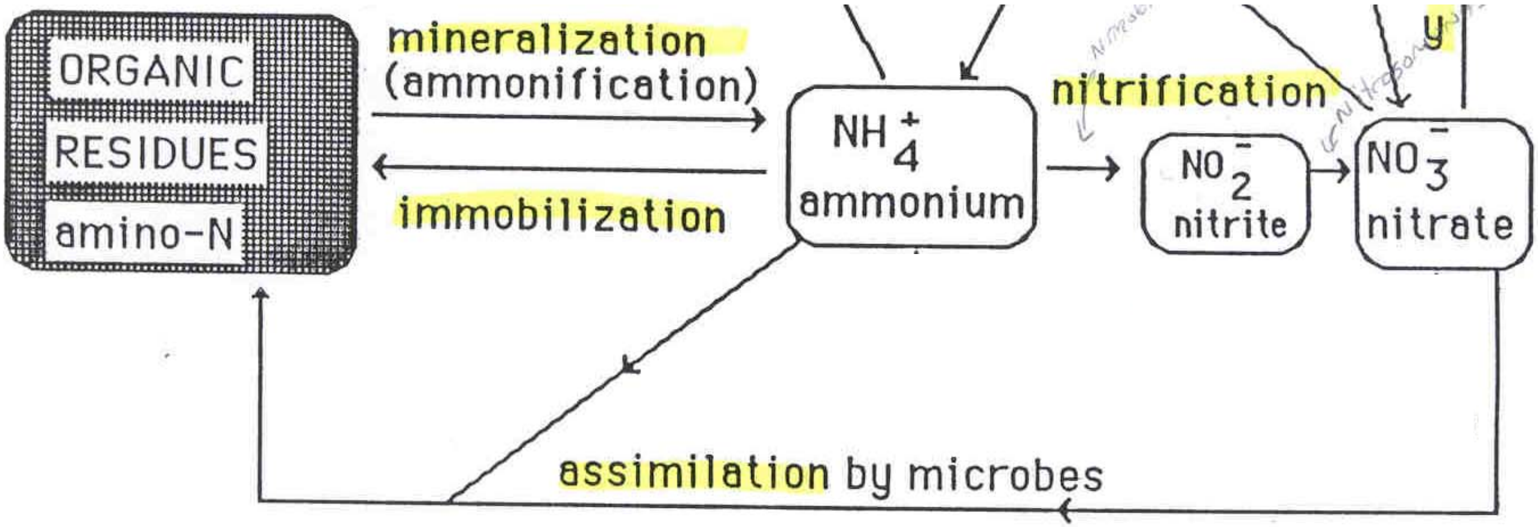
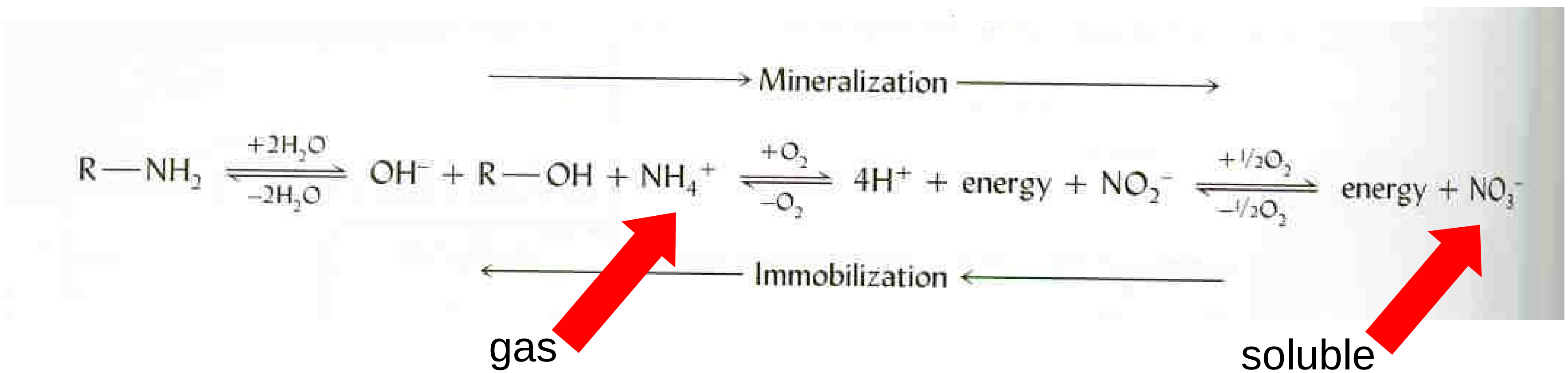


Fig. 4.1
The N cycle in soil. (From Stevenson.[1])

The Nitrogen Cycle



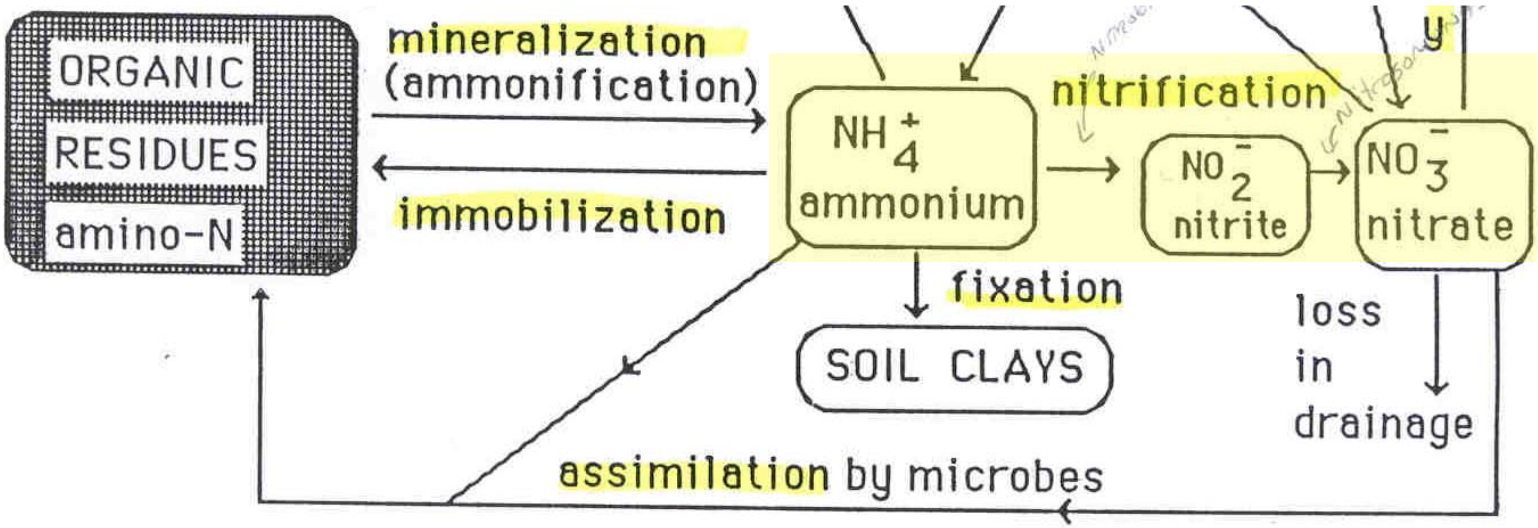




Mineralization = 2 components

1) ammonification

2) nitrification



Step 1

$$NH_4^+ + 1\,{}^1/_2O_2 \xrightarrow[\text{bacteria}]{\textit{Nitrosomonas}} NO_2^- + 2H^+ + H_2O + 275 \text{ kJ energy}$$

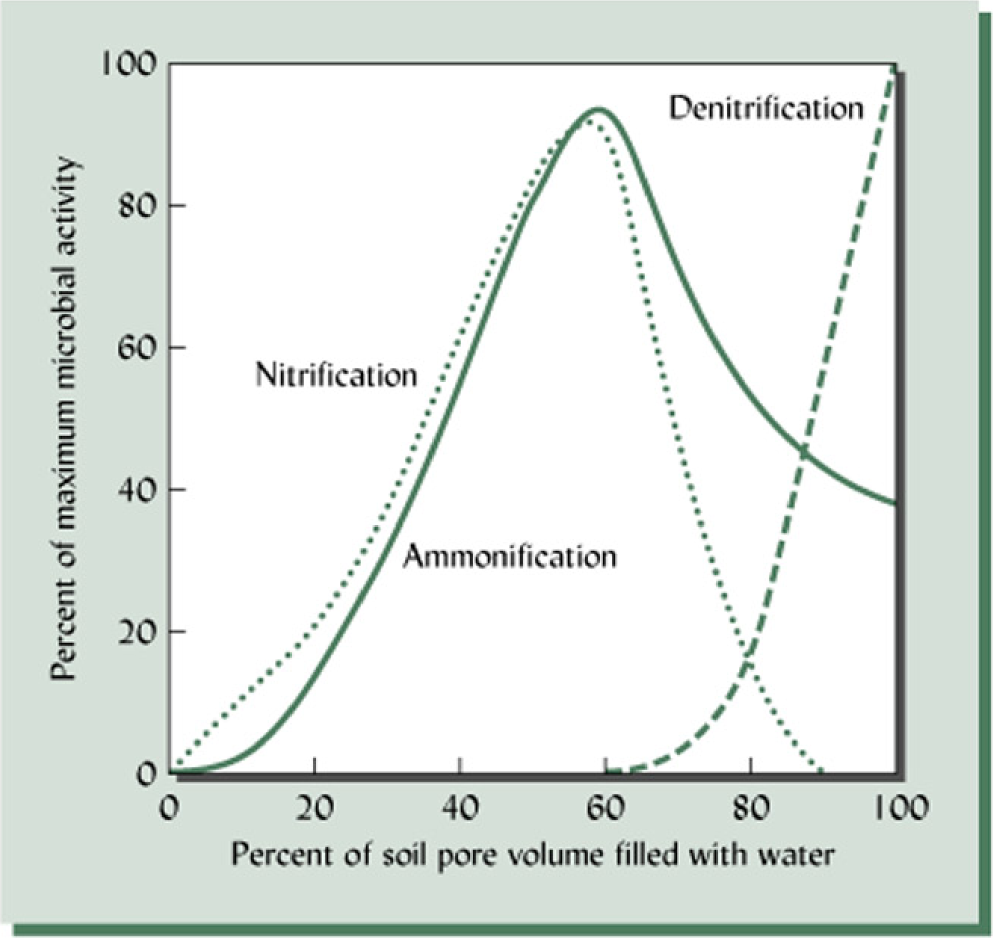
Ammonium → Nitrite

Step 2

$$NO_2^- + {}^1/_2O_2 \xrightarrow[\text{bacteria}]{\textit{Nitrobacter}} NO_3^- + 76 \text{ kJ energy}$$

Nitrite → Nitrite

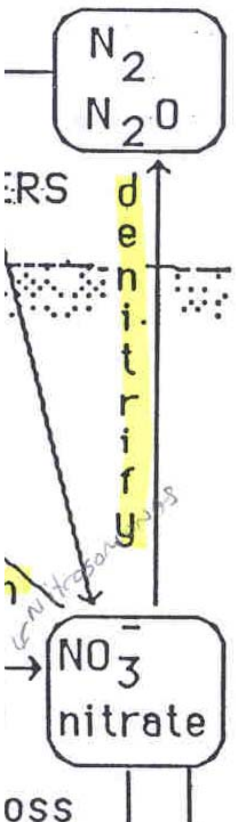
Soluble



100
80
60
40
20
0
Percent of maximum microbial activity
Denitrification
Nitrification
Ammonification
0
20
40
60
80
100
Percent of soil pore volume filled with water

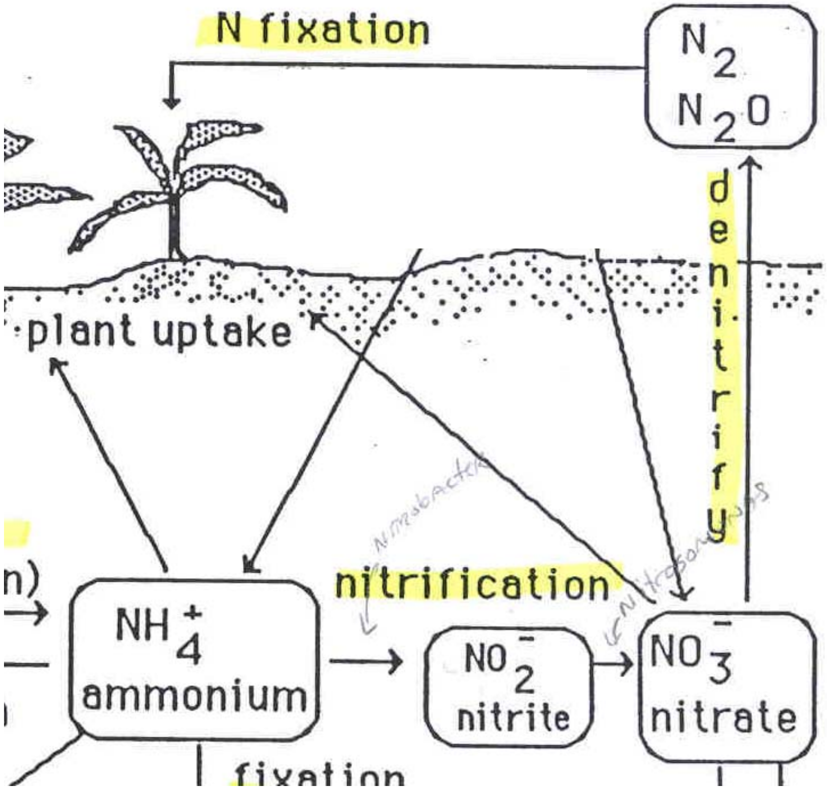
$$2NO_3^- \xrightarrow{-2[O]} 2NO_2^- \xrightarrow{-2[O]} 2NO\uparrow \xrightarrow{-[O]} N_2O\uparrow \xrightarrow{-[O]} N_2\uparrow$$

Nitrate ions	Nitrite ions	Nitric oxide gas	Nitrous oxide gas	Dinitrogen gas
(+5)	(+3)	(+2)	(+1)	(0)



Gases

Getting N into the plant (2 pathways)…
where it ultimately gets to higher trophic levels



(2) Plant uptake

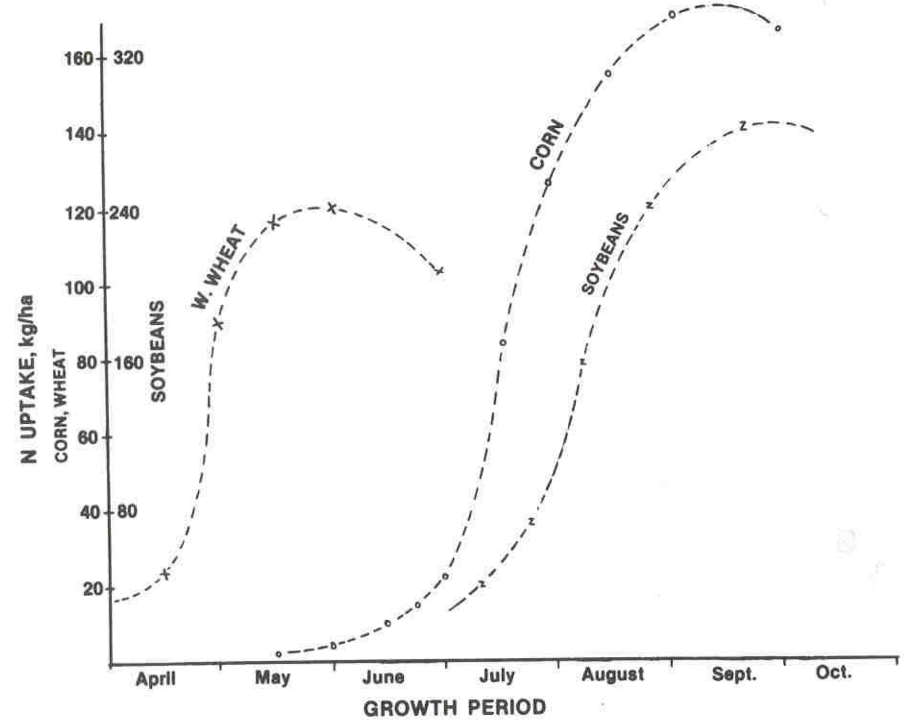


Fig. 4.5
Average rates of N accumulation in the above-ground crop of nonirrigated wheat and irrigated corn and soybeans in Nebraska.[13] (Reproduced from *Nitrogen in Agricultural Soils* (1982) by permission of the American Society of Agronomy.)

(1) N Fixation

$$N_2 + 6H^+ \longrightarrow 2NH_3$$

NITROGEN CYCLE AND FERTILITY

CYCLE implies that no N fertilizer would ever be needed.

BUT CYCLE has "leaks":

EROSION - loss of organic N in litter & humus

HARVESTING - removal of organic N in biomass

LEACHING - removal of NO_3^- (mostly) and NH_4^+ (partly)

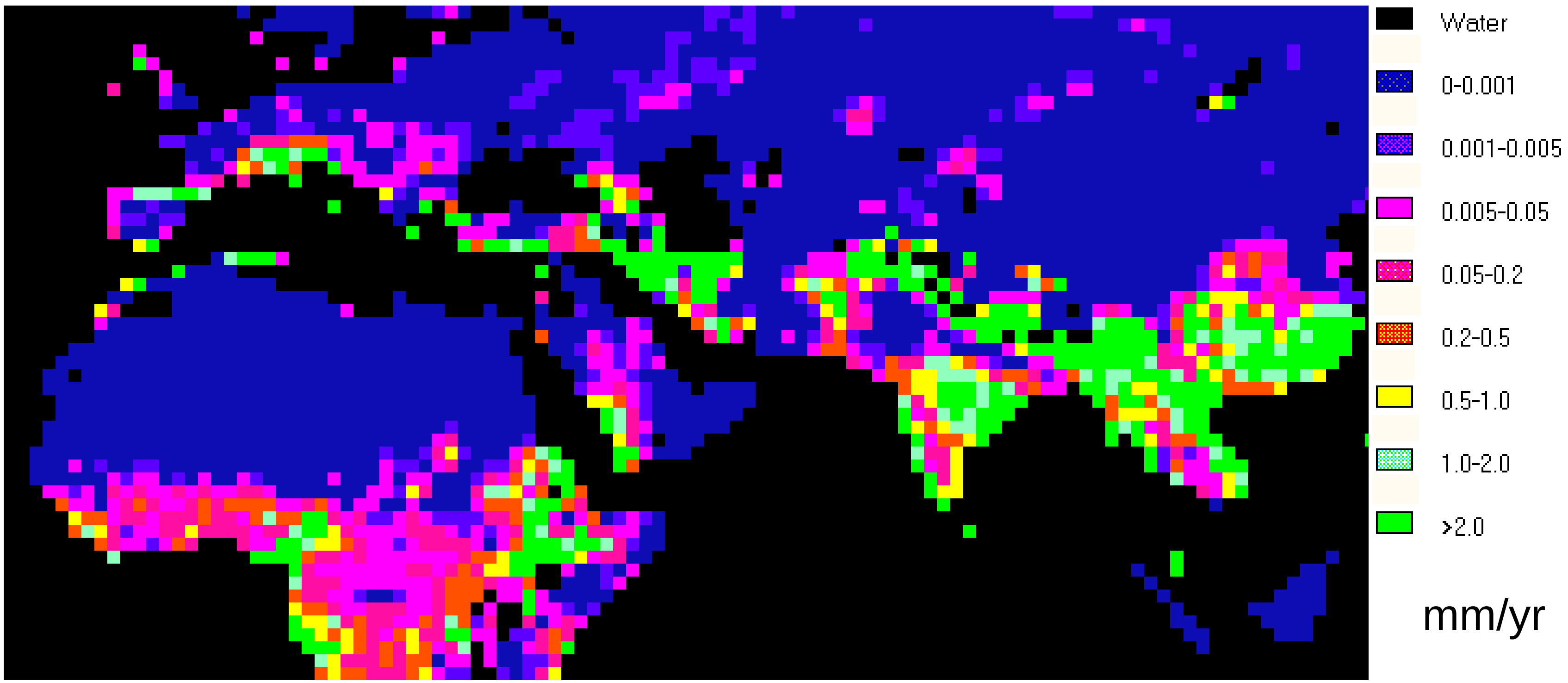
DENITRIFICATION - NO_3^- conversion to gases which escape soil

BURNING OF SOIL - converts organic N to gases

These leaks are offset by:

FERTILIZER N
BIOLOGICAL FIXATION OF N_2

Soil Erosion



Harvesting

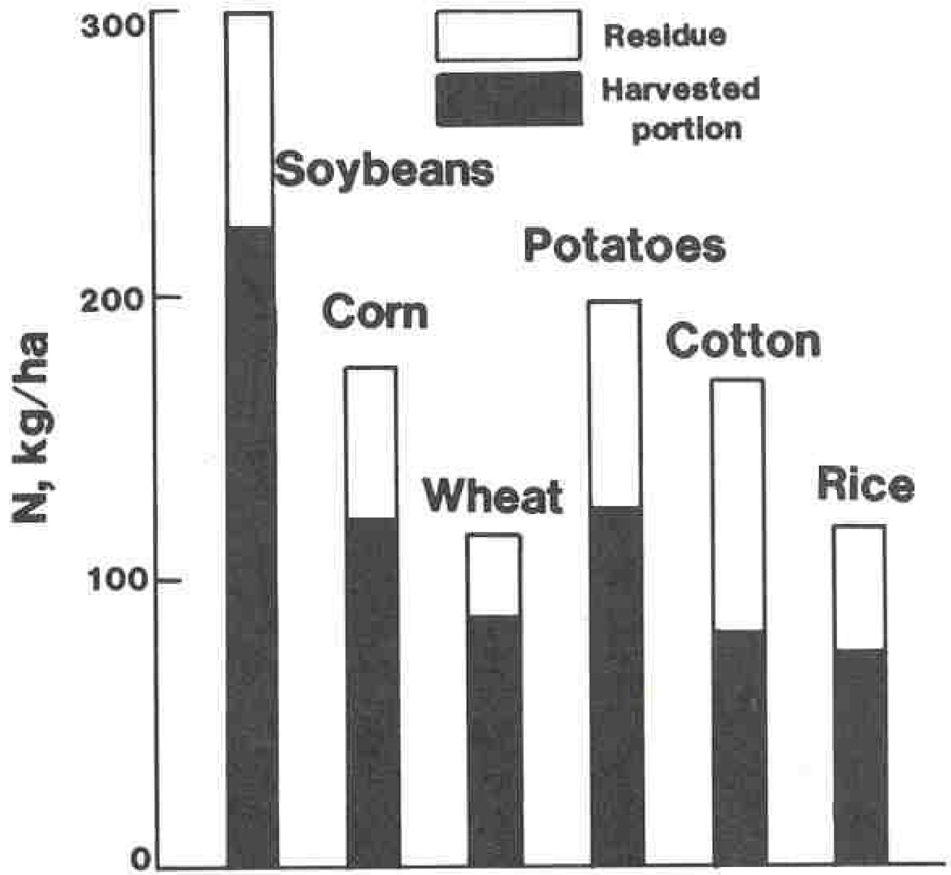
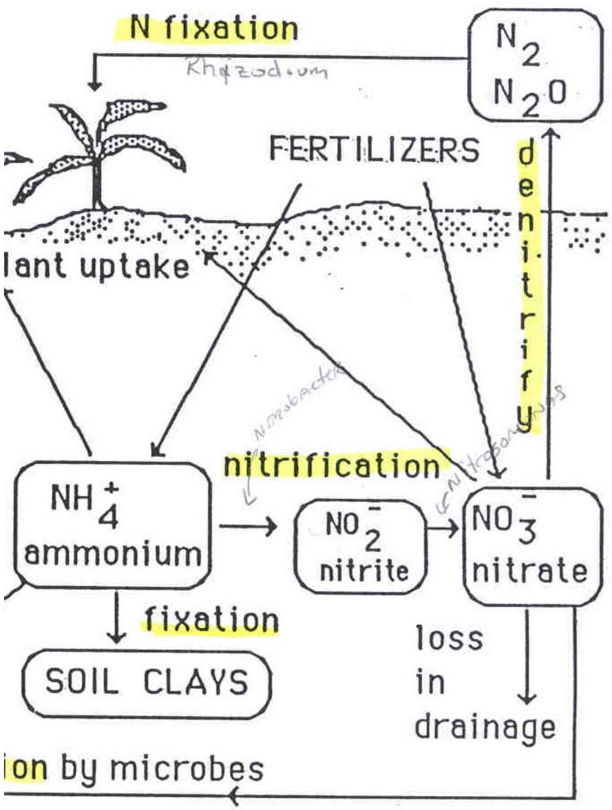
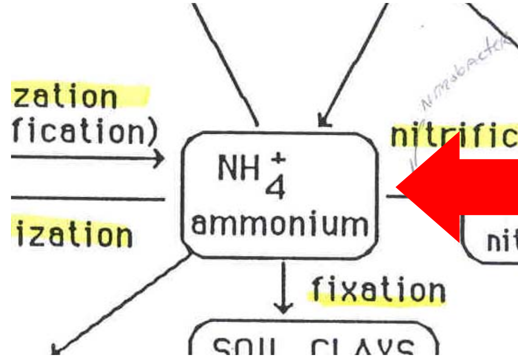


Fig. 4.4

Nitrogen contained in the harvested portion and residue of good yields of some major agricultural crops. (Adapted from Olson and Kurtz.[13])

Leaching and Denitrification





Gas

Soluble

Step 1

$$NH_4^+ + 1\,{}^1\!/_2O_2 \xrightarrow[\text{bacteria}]{\textit{Nitrosomonas}} NO_2^- + 2H^+ + H_2O + 275 \text{ kJ energy}$$

Ammonium — Nitrite

Step 2

$$NO_2^- + {}^1\!/_2O_2 \xrightarrow[\text{bacteria}]{\textit{Nitrobacter}} NO_3^- + 76 \text{ kJ energy}$$

Nitrite — Nitrite

$$2NO_3^- \xrightarrow{-2[O]} 2NO_2^- \xrightarrow{-2[O]} 2NO\uparrow \xrightarrow{-[O]} N_2O\uparrow \xrightarrow{-[O]} N_2\uparrow$$

Nitrate ions	Nitrite ions	Nitric oxide gas	Nitrous oxide gas	Dinitrogen gas
(+5)	(+3)	(+2)	(+1)	(0)

HYPOTHESIS #1

INHERENT NITROGEN FERTILITY, LIKE THE SOIL ORGANIC MATTER LEVEL, IS IMPROVED MOST EFFECTIVELY BY <u>RESIDUE CONSERVATION</u> COMBINED WITH AGRICULTURAL PRACTICES THAT SUSTAIN THE HIGHEST YIELD (i.e. BIOMASS PRODUCTION)

HYPOTHESIS #2

EVEN WITH HIGH SOIL ORGANIC MATTER, MINERALIZATION RARELY IS FAST ENOUGH TO MEET DEMANDS OF VIGOROUSLY GROWING CROPS.

Farmers can enhance N fertility by:

- **Supplementing with N fertilizers**
- **Promoting biological N fixation**
- **Minimizing NO_3^- leaching**
- **Minimizing denitrification**