



Fundamentals of Soil Nutrient Dynamics

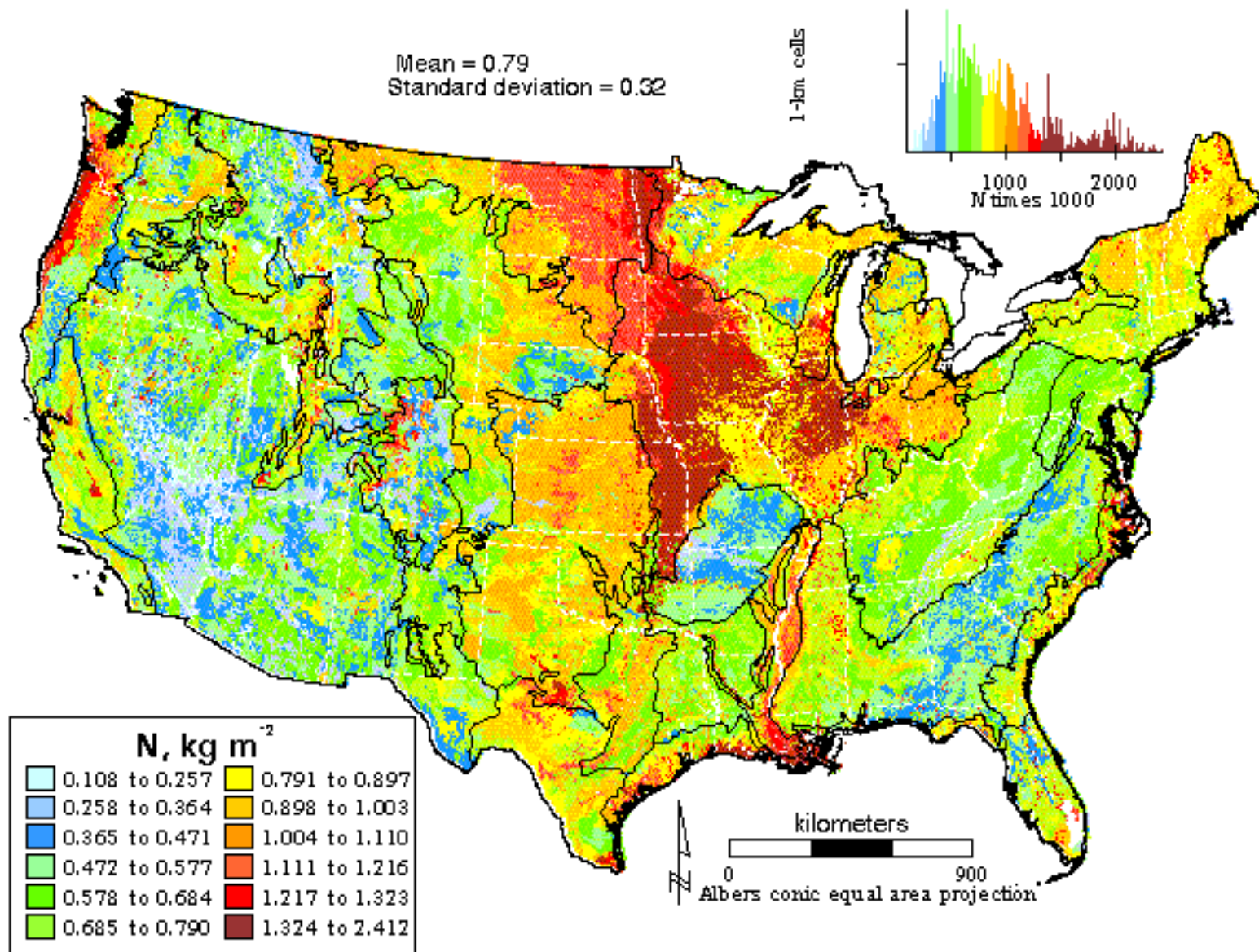
Steven Perakis

N_2



P, S, Ca, Mg, K, Mo, Fe,

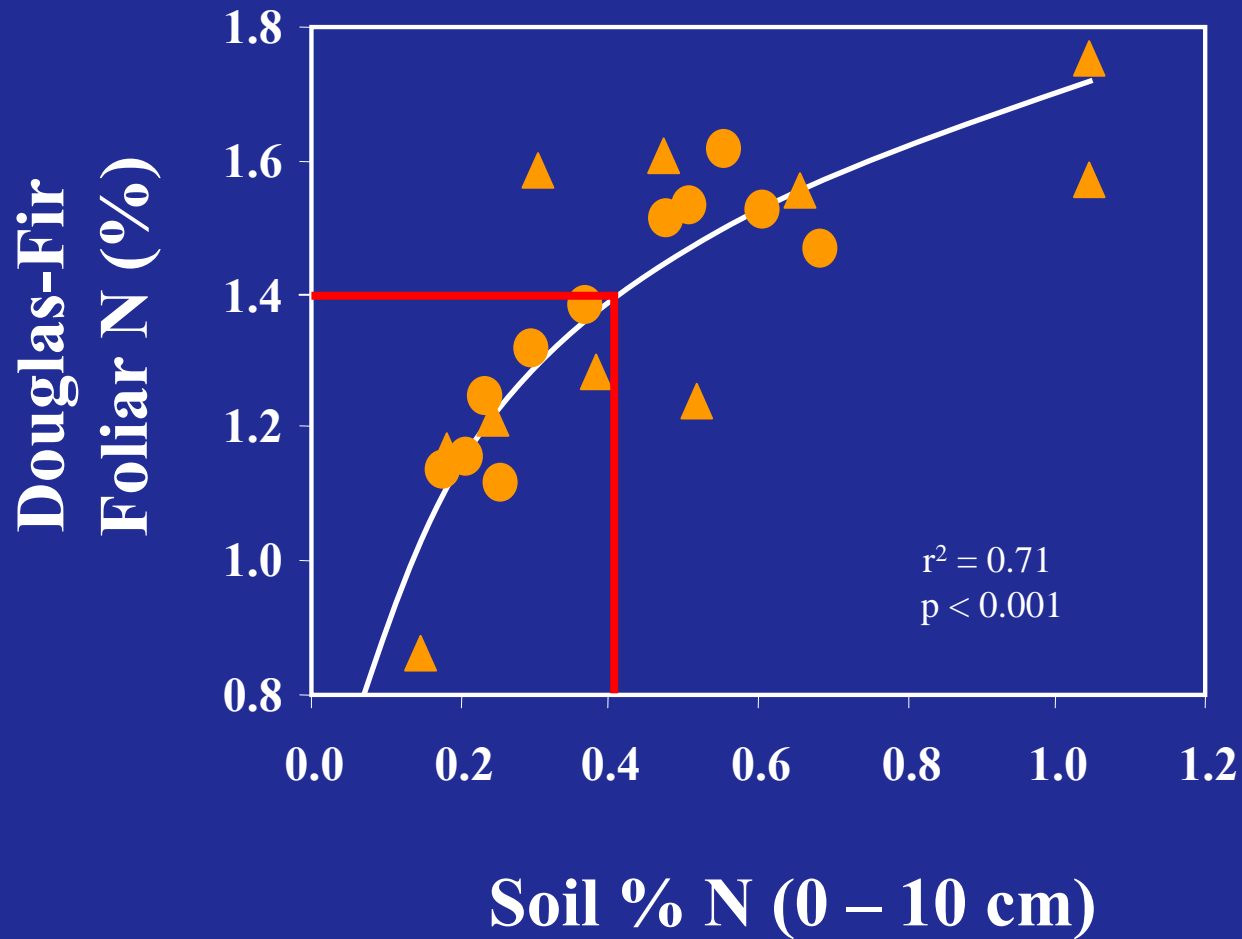




Nitrogen content of mineral soil in the 0- to 100-cm depth layer for the contiguous US with Land Resource Region boundaries.

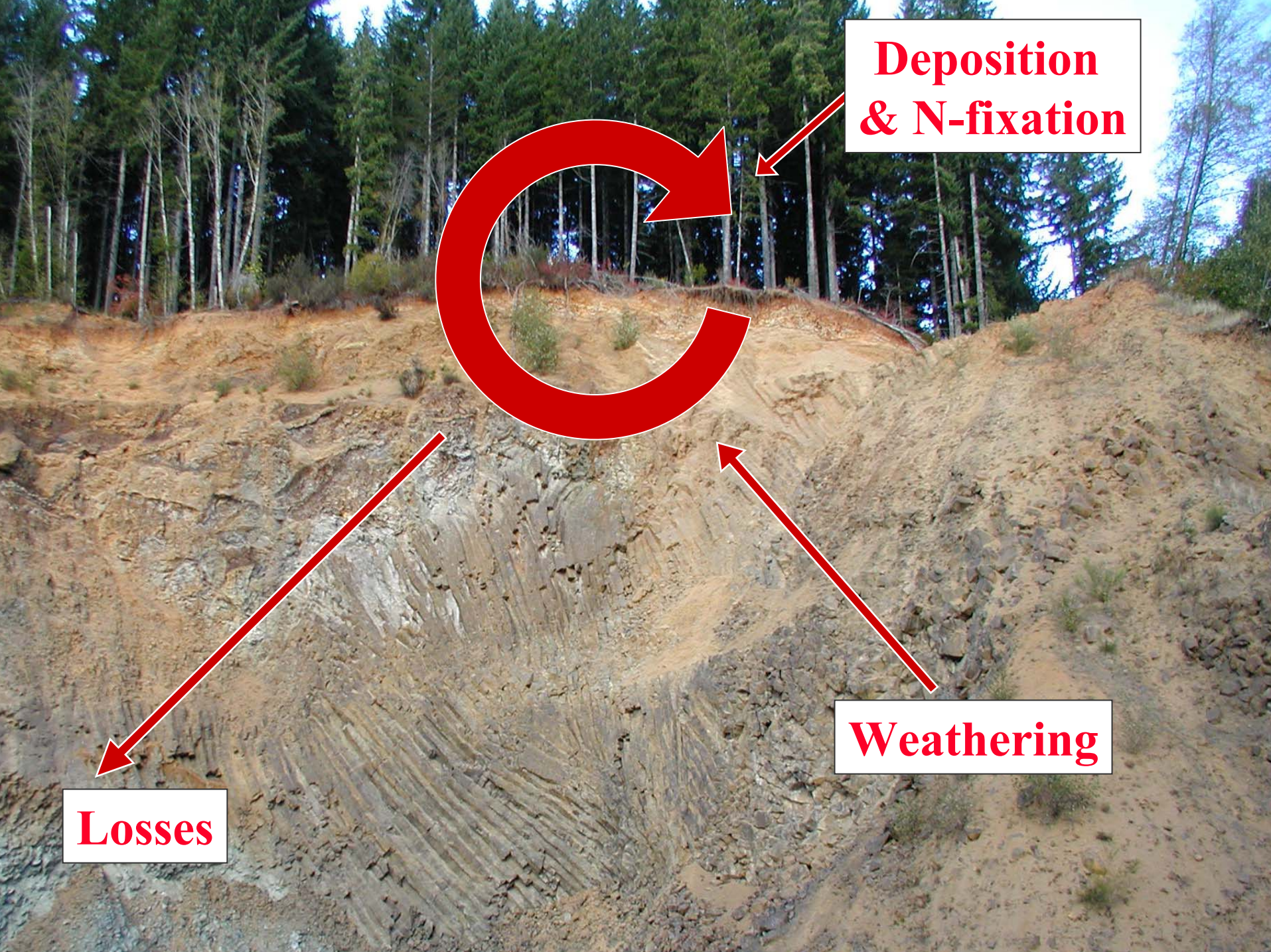
J. S. Kem
13 Aug 98

N-Rich Soils Grow N-Rich Plants



Nutritional Issues at Nitrogen-Rich Sites

- Phosphorus
- Sulfur
- Calcium, Magnesium, Potassium (base cations)
- Aluminum toxicity
- Micro-nutrients (Fe, Bo, Mn, Cu, Zn...)
- No deficiency



**Deposition
& N-fixation**

Weathering

Losses

Phosphorus (P)

Periodic Table of the Elements

H Hydrogen 1																	He Helium 2
Li Lithium 3	Be Beryllium 4											B Boron 5	C Carbon 6	N Nitrogen 7	O Oxygen 8	F Fluorine 9	Ne Neon 10
Na Sodium 11	Mg Magnesium 12											Al Aluminum 13	Si Silicon 14	P Phosphorus 15	S Sulfur 16	Cl Chlorine 17	Ar Argon 18
K Potassium 19	Ca Calcium 20	Sc Scandium 21	Ti Titanium 22	V Vanadium 23	Cr Chromium 24	Mn Manganese 25	Fe Iron 26	Co Cobalt 27	Ni Nickel 28	Cu Copper 29	Zn Zinc 30	Ga Gallium 31	Ge Germanium 32	As Arsenic 33	Se Selenium 34	Br Bromine 35	Kr Krypton 36
Rb Rubidium 37	Sr Strontium 38	Y Yttrium 39	Zr Zirconium 40	Nb Niobium 41	Mo Molybdenum 42	Tc Technetium 43	Ru Ruthenium 44	Rh Rhodium 45	Pd Palladium 46	Ag Silver 47	Cd Cadmium 48	In Indium 49	Sn Tin 50	Sb Antimony 51	Te Tellurium 52	I Iodine 53	Xe Xenon 54
Cs Cesium 55	Ba Barium 56	★ Lanthanum 57	Hf Hafnium 72	Ta Tantalum 73	W Tungsten 74	Re Rhenium 75	Os Osmium 76	Ir Iridium 77	Pt Platinum 78	Au Gold 79	Hg Mercury 80	Tl Thallium 81	Pb Lead 82	Bi Bismuth 83	Po Polonium 84	At Astatine 85	Rn Radon 86
Fr Francium 87	Ra Radium 88	★★ Actinium 89	Rf Rutherfordium 104	Db Dubnium 105	Sg Seaborgium 106	Bh Bohrium 107	Hs Hassium 108	Mt Meitnerium 109	Uun Ununennium 110	Uuu Ununennium 111	Uub Unbinilium 112						

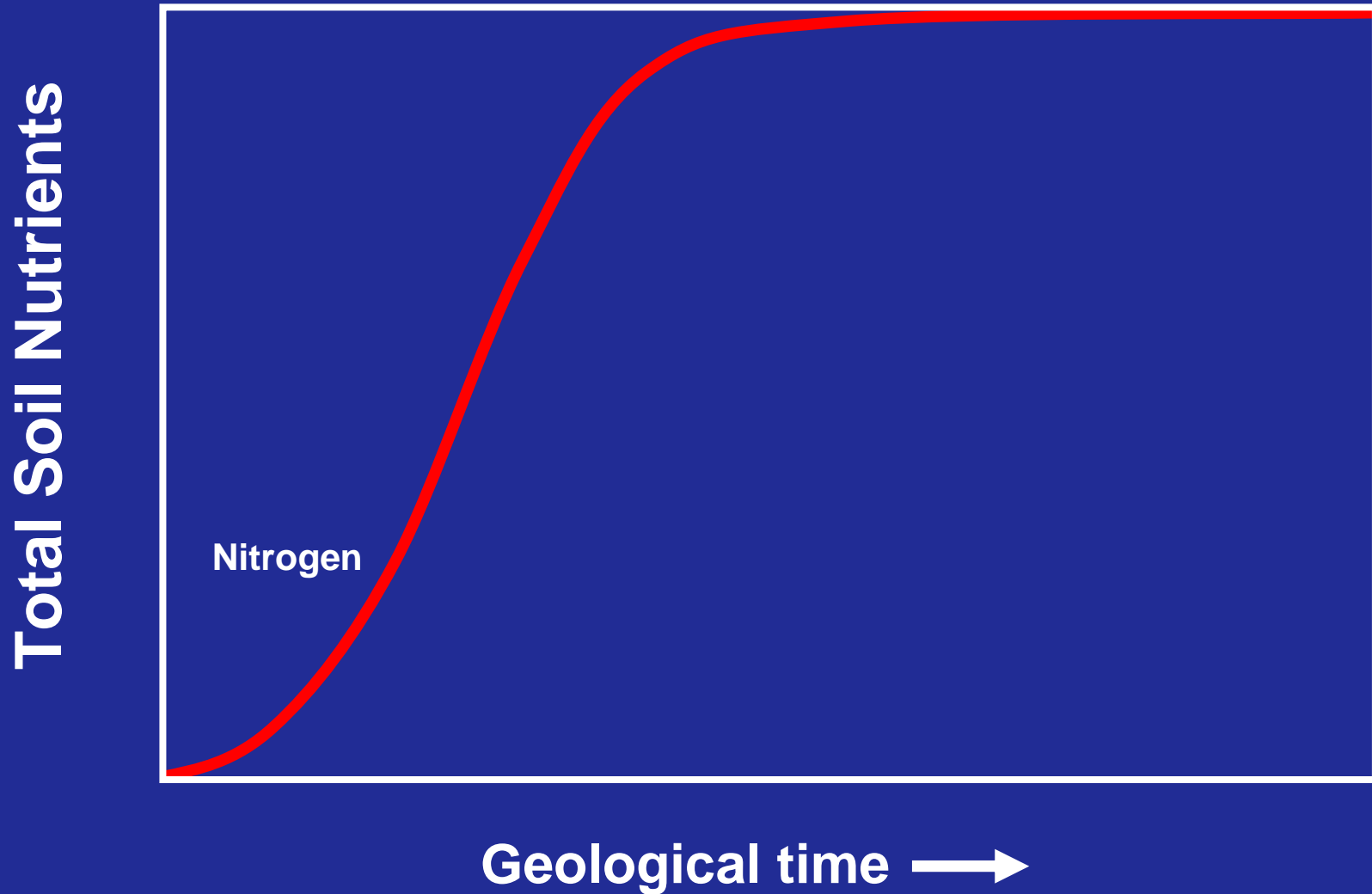
- Alkali Earth Metals
- Alkaline Earth Metals
- Transition Metals
- Rare Earth Metals
- Other Metals
- Metalloids
- Non-Metals
- Halogens
- Noble Gases

La Lanthanum 57	Ce Cerium 58	Pr Praseodymium 59	Nd Neodymium 60	Pm Promethium 61	Sm Samarium 62	Eu Europium 63	Gd Gadolinium 64	Tb Terbium 65	Dy Dysprosium 66	Ho Holmium 67	Er Erbium 68	Tm Thulium 69	Yb Ytterbium 70	Lu Lutetium 71
Ac Actinium 89	Th Thorium 90	Pa Protactinium 91	U Uranium 92	Np Neptunium 93	Pu Plutonium 94	Am Americium 95	Cm Curium 96	Bk Berkelium 97	Cf Californium 98	Es Einsteinium 99	Fm Fermium 100	Md Mendelevium 101	No Nobelium 102	Lr Lawrencium 103

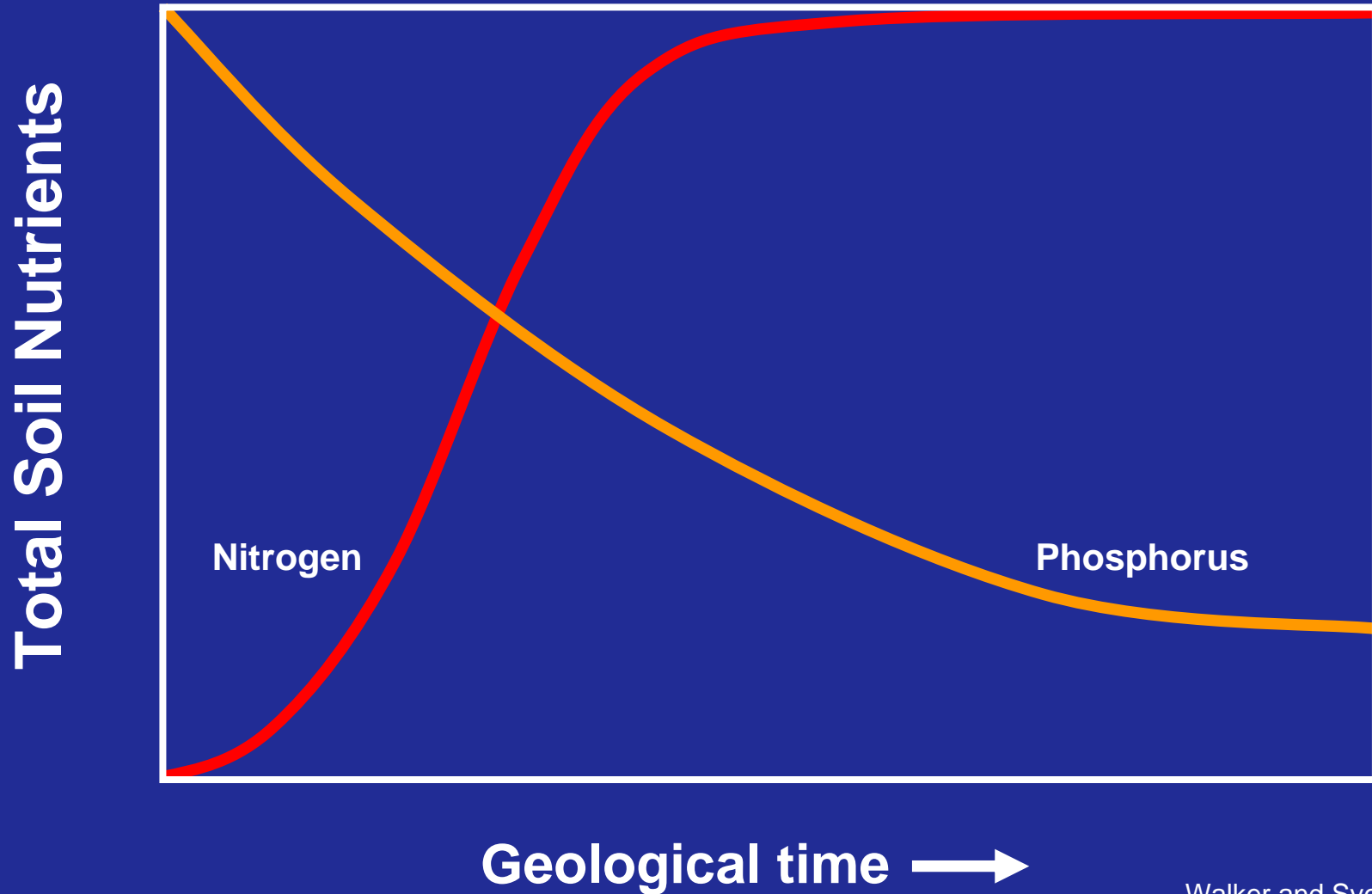
Phosphorus (P)

- **Source: Apatite**
- **PO_4^{3-} (H_2PO_4^- in forest soils)**
- **Chemically sticky (especially in Andic soils)**
 - **Iron (Fe^{3+}), Aluminum (Al^{3+}) – *insoluble!***
- **Cycles readily through organic matter**

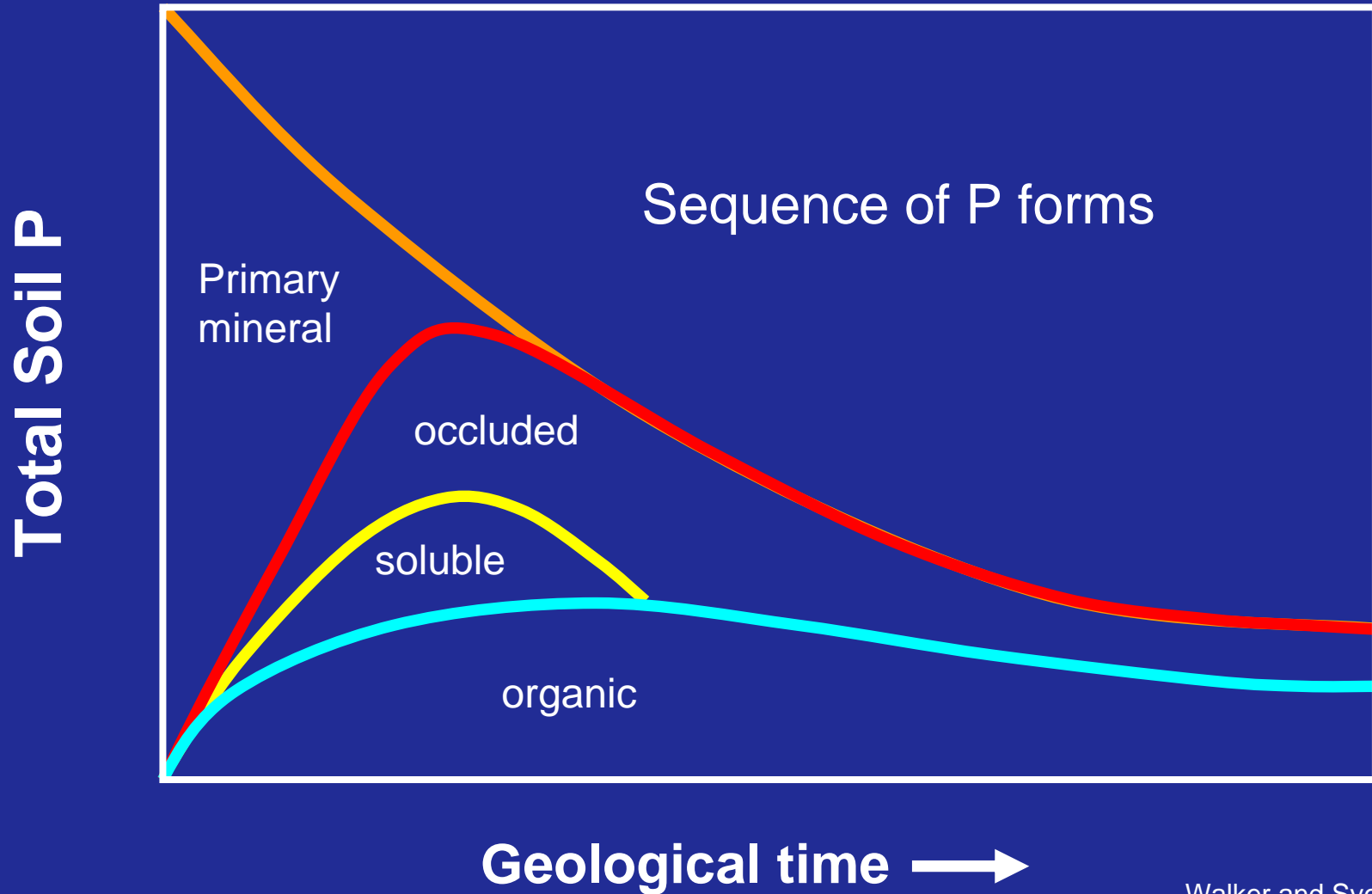
Nitrogen Accumulation



Phosphorus Depletion



Phosphorus Forms in Soils



Sulfur (S)

Periodic Table of the Elements

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	★	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	★★	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						

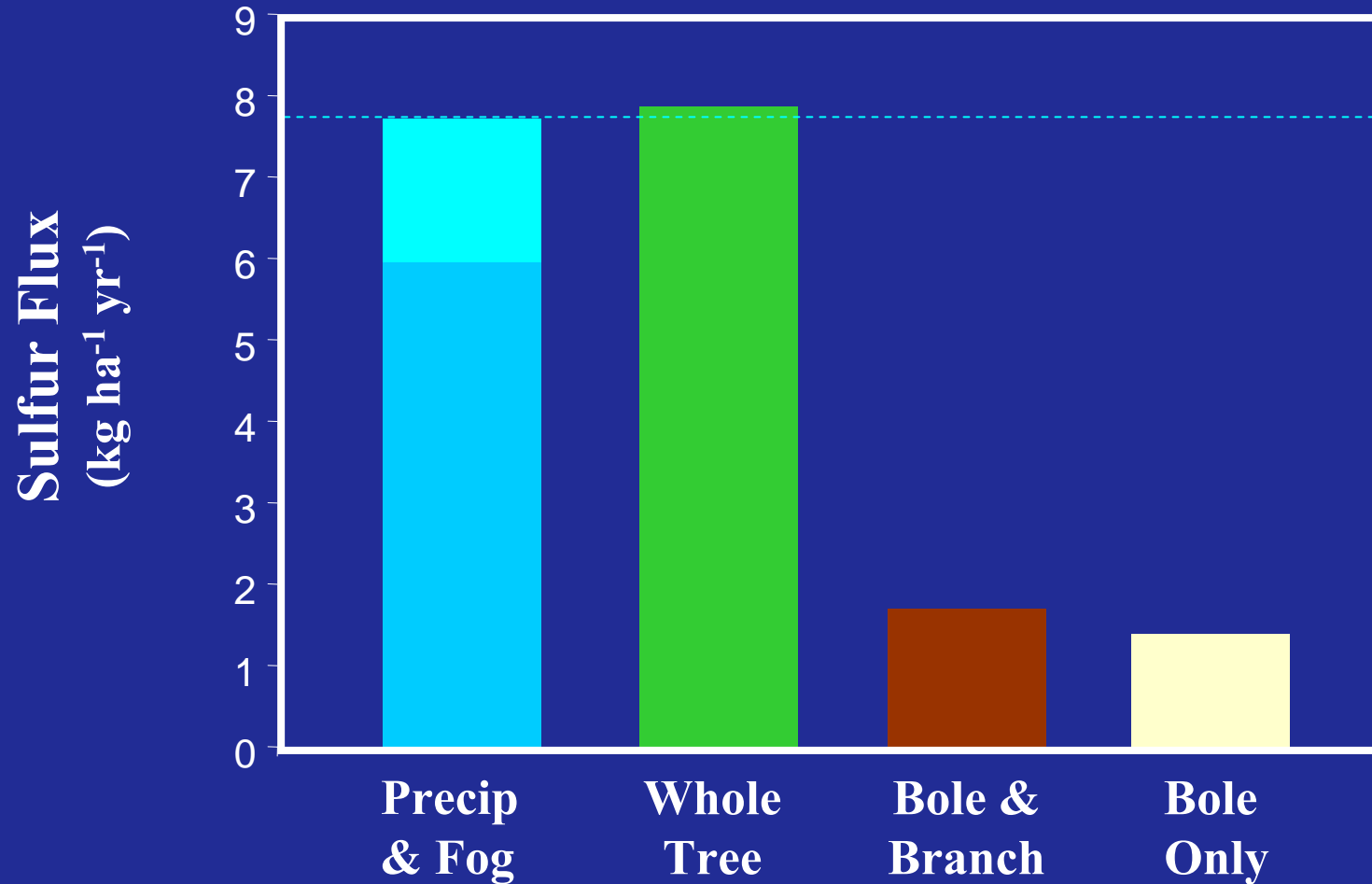
- Alkali Earth Metals
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- Other Metals
- Metalloids
- Non-Metals
- Halogens
- Noble Gases

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

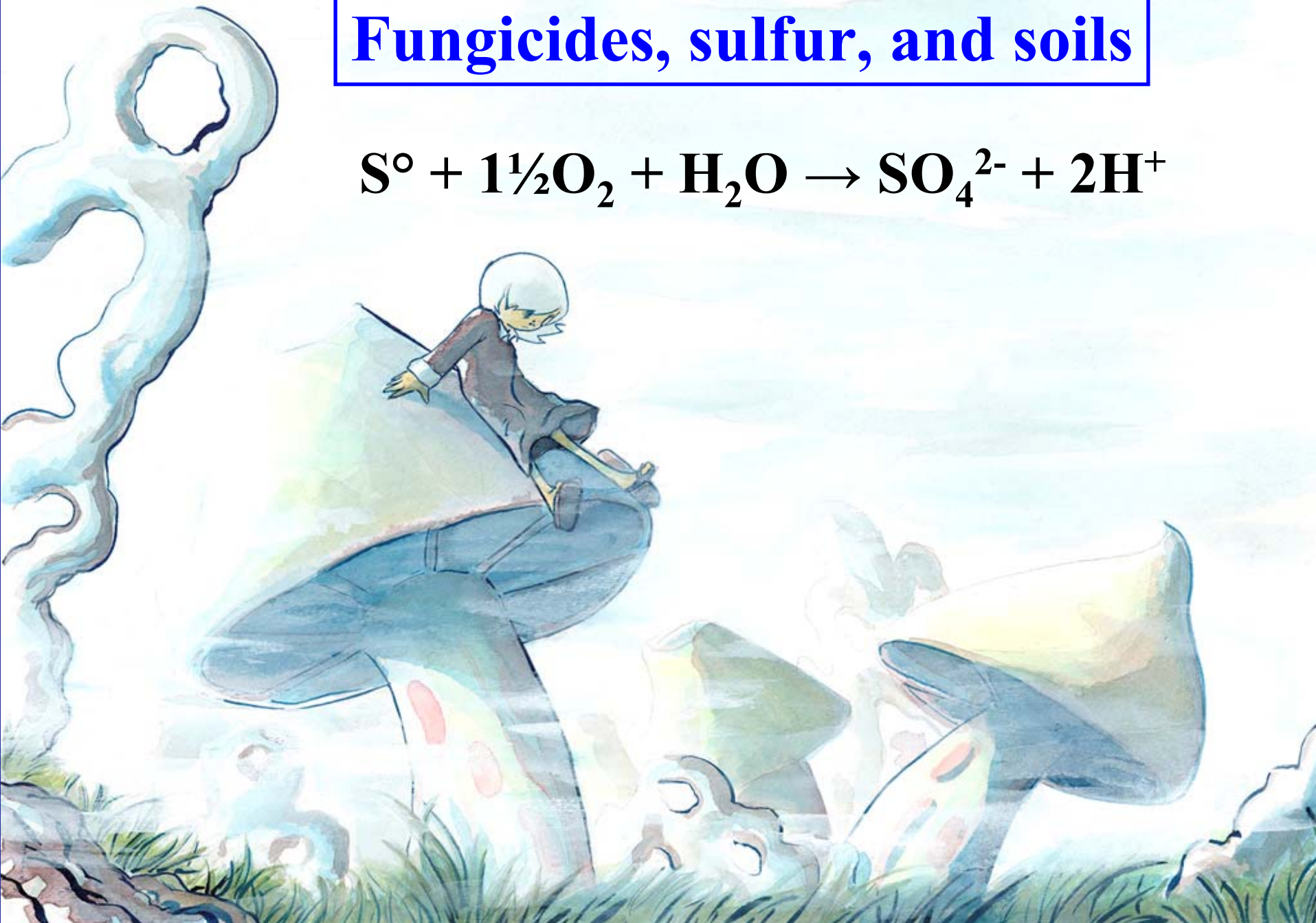
Sulfur (S)

- **Source: Pyrite and Gypsum, Seawater**
- SO_4^{2-}
- **Somewhat chemically sticky**
 - Iron, Aluminum, Calcium – *soluble!*
- **Cycles readily through organic matter**

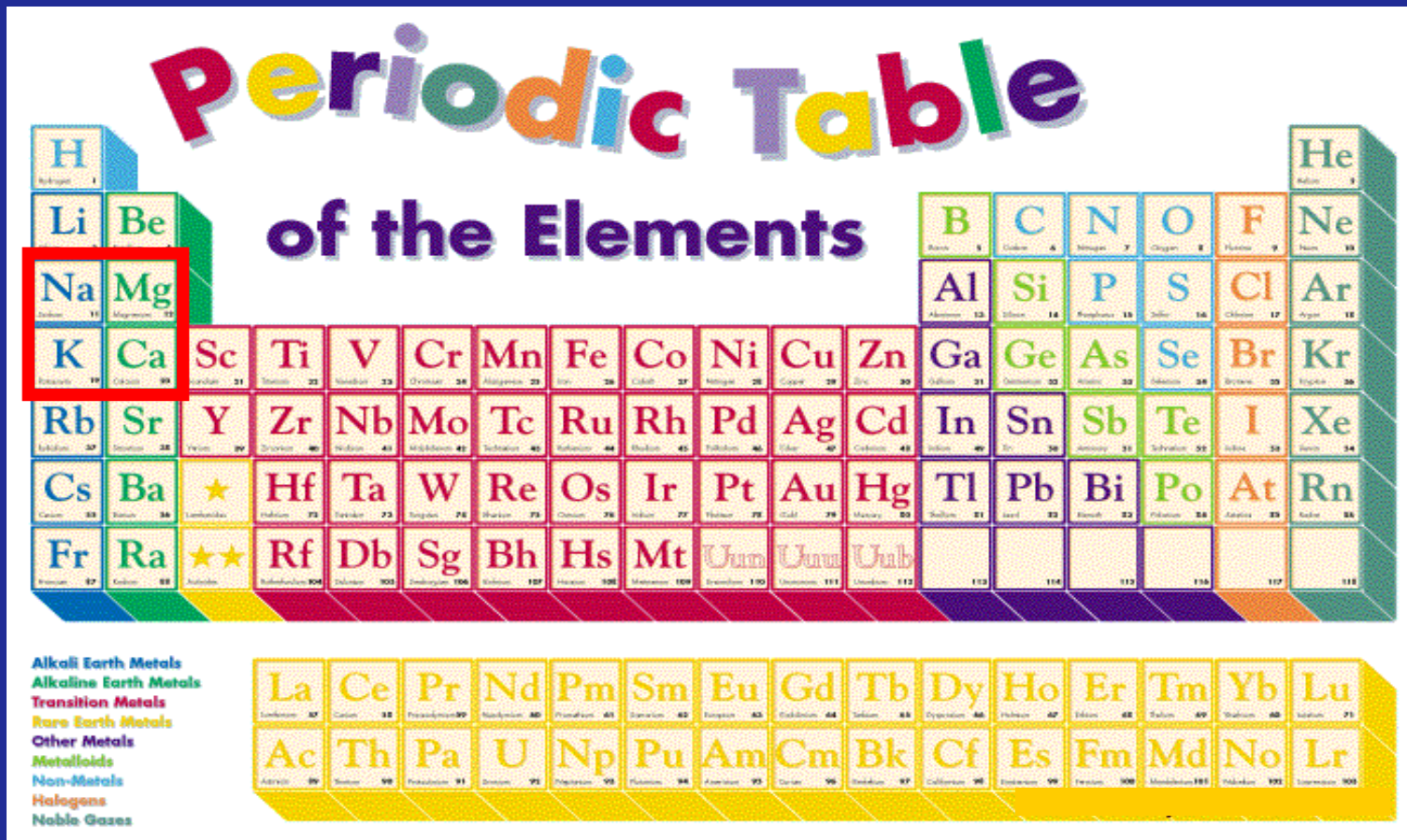
Sulfur Inputs compared to Tree Uptake



Fungicides, sulfur, and soils



Calcium (Ca), Magnesium (Mg) Potassium (K)



Base Cations - Ca, Mg, K

- **Source: Many minerals, Seawater**
- **Ca^{2+} , Mg^{2+} , K^{+}**
- **Very loosely held in soils**
 - **Ion exchange on organic matter and clays**
- **Very soluble and subject to leaching in acid soils**

Base Cations in Soils

Cation exchange capacity

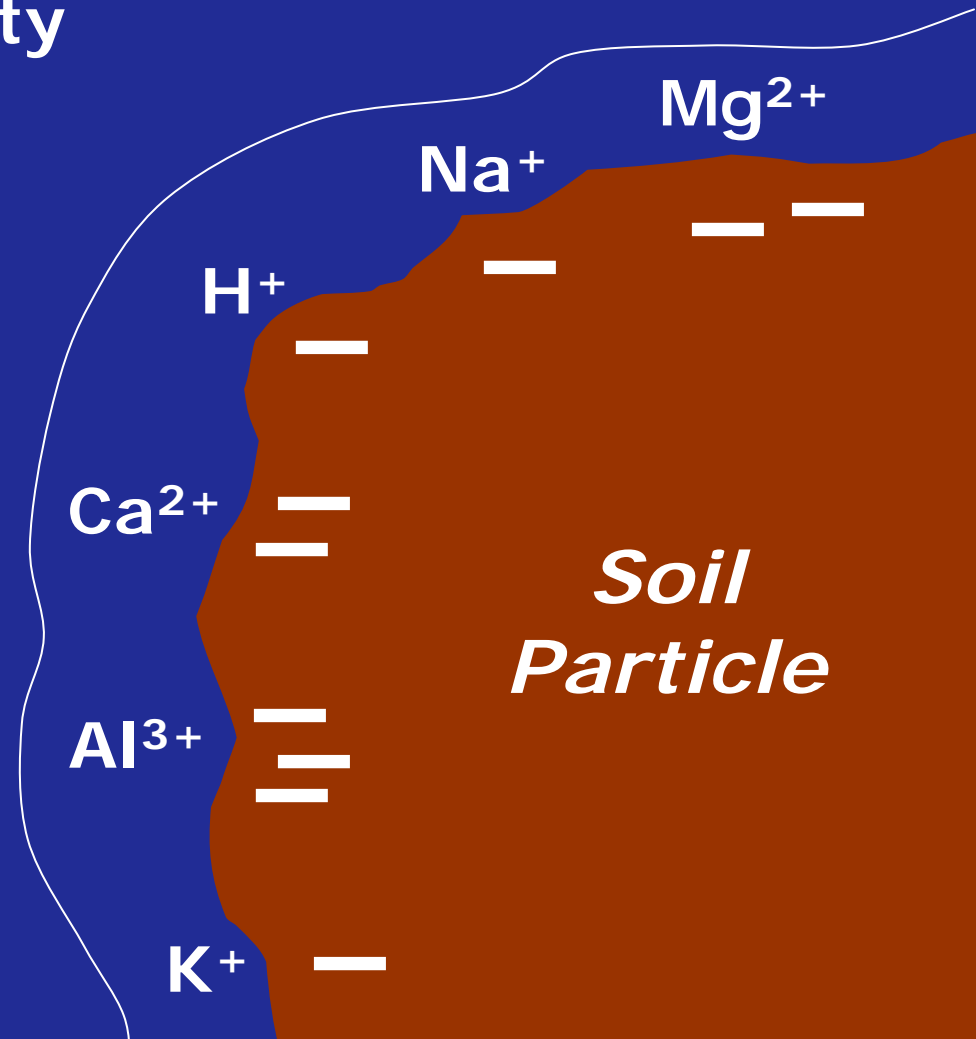
= sum of negative charges

Base saturation

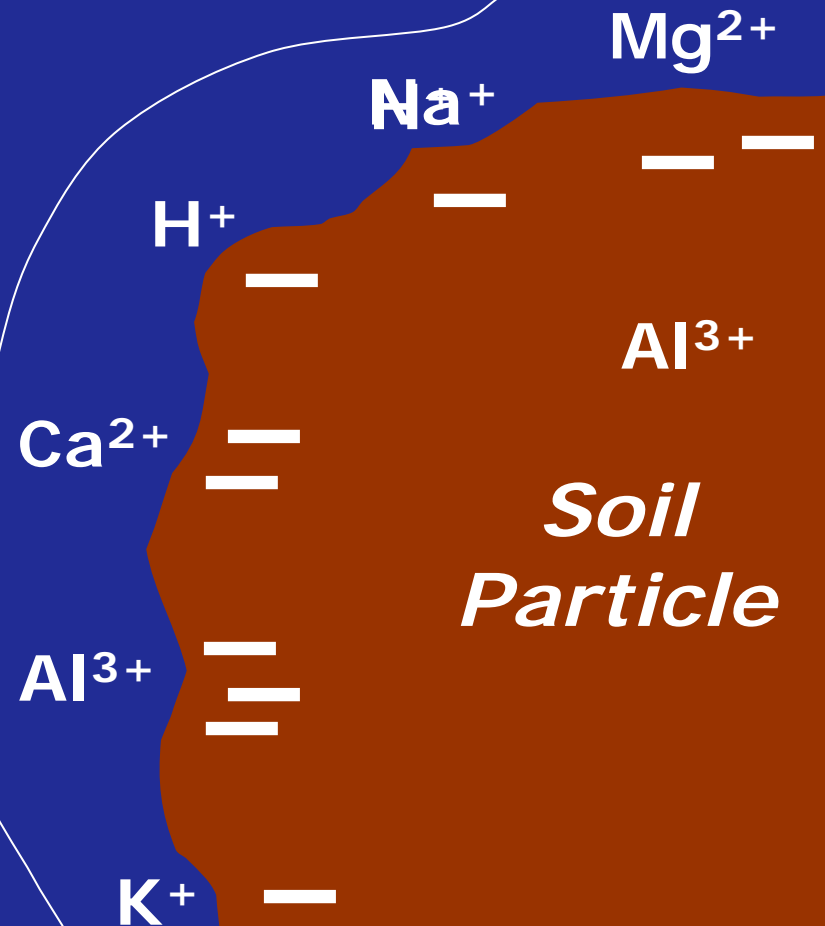
% occupied by Ca+Mg+K+Na

Displacement series

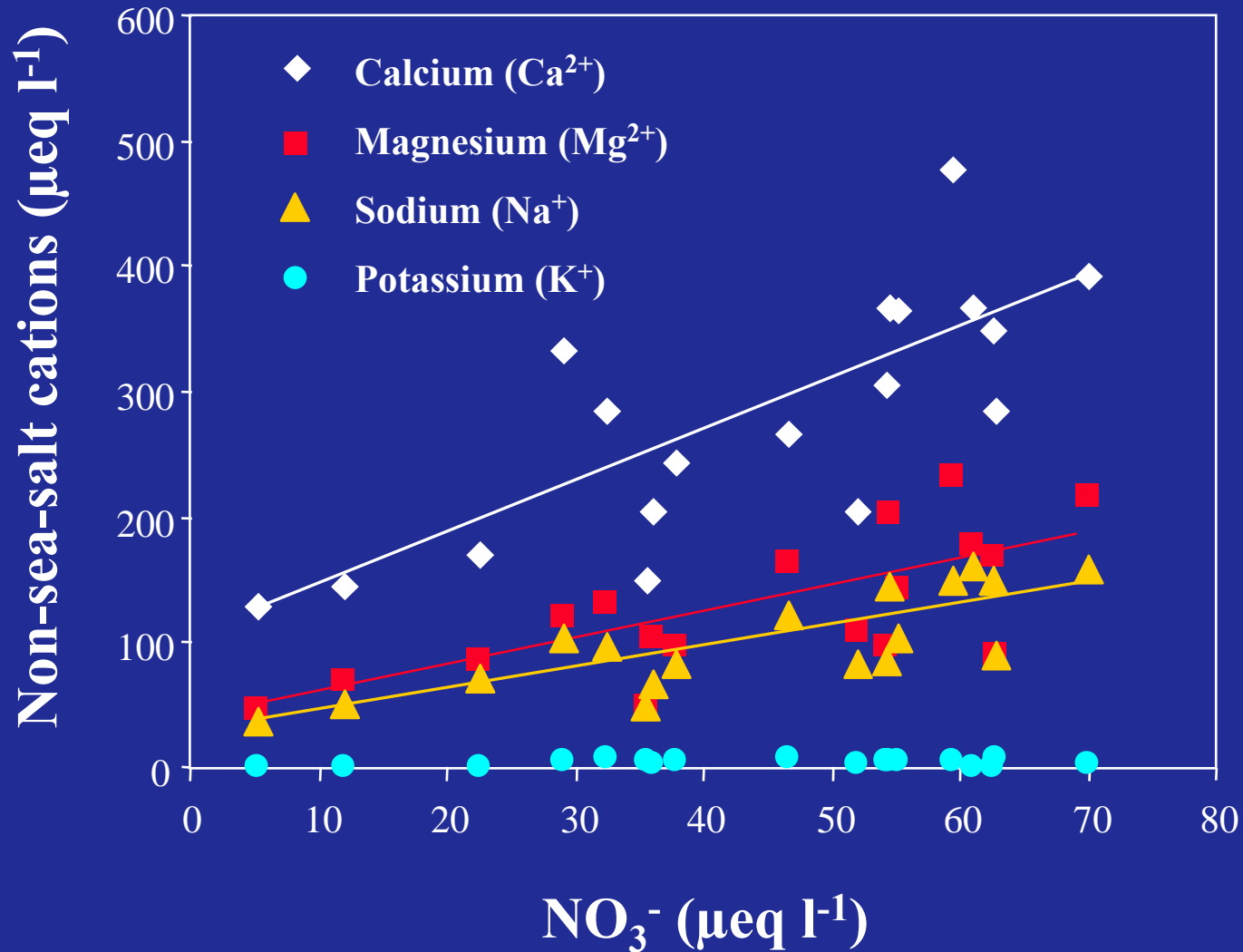
$H(Al^{3+}) > H^+ > Ca^{2+} > Mg^{2+} >$
 $> K^+ = NH_4^+ > Na^+$

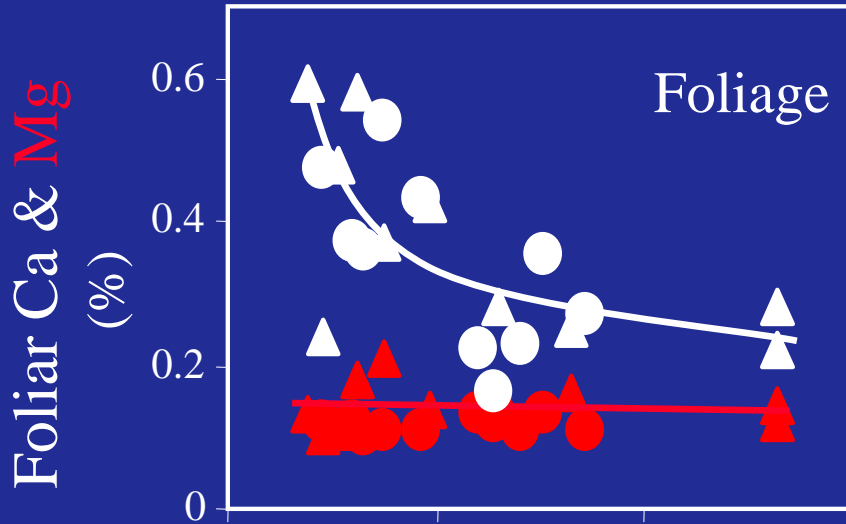


Base Cation Leaching

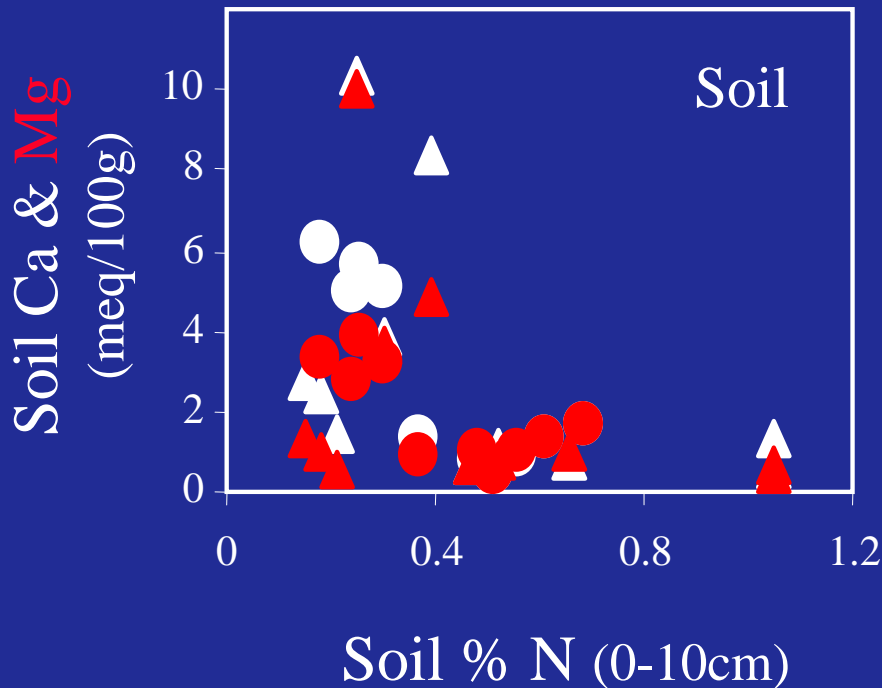


Coupled Nitrate & Base Cation Leaching



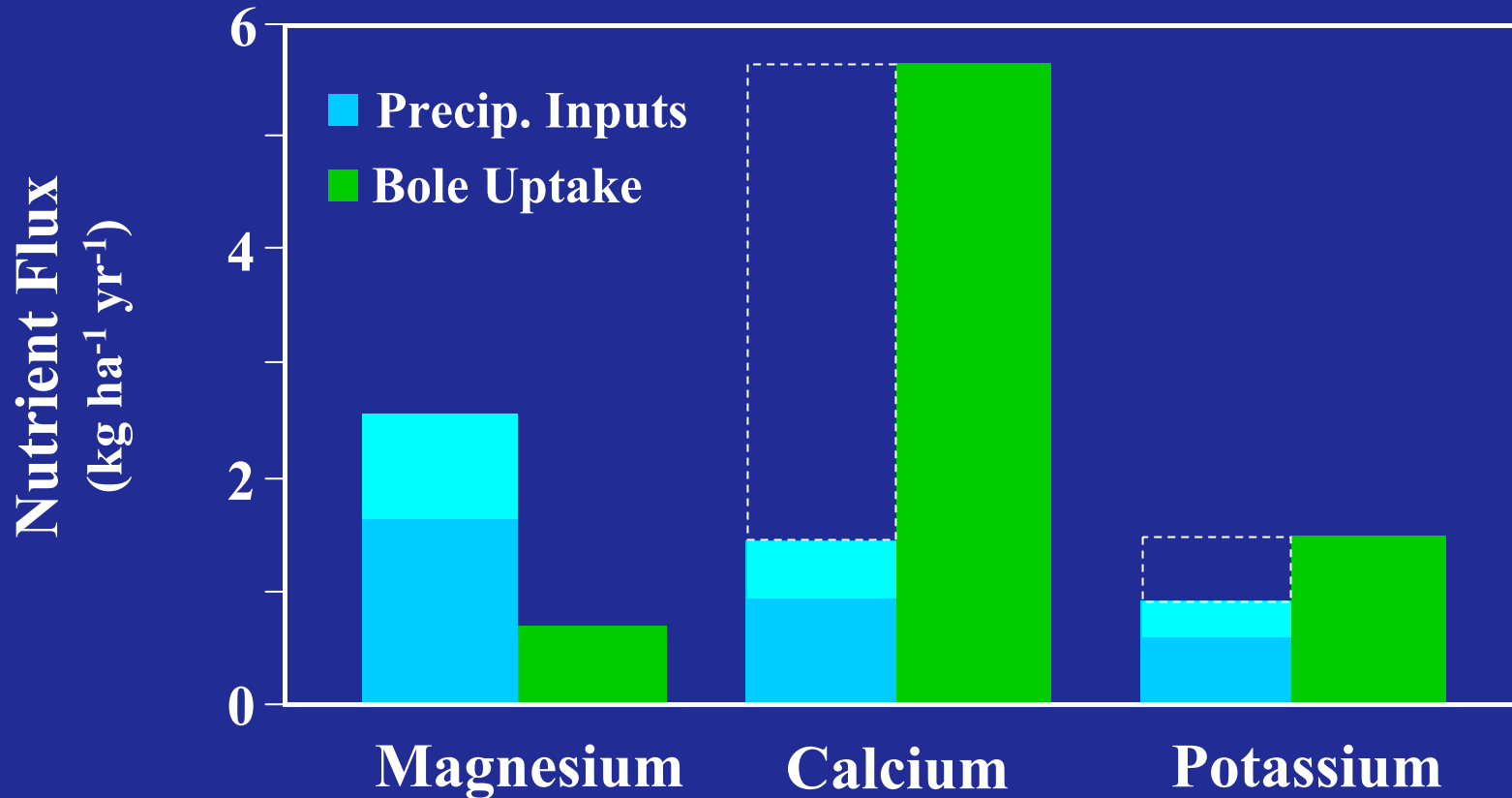


Foliar Calcium tracks
soil Calcium



High soil N drives
low soil calcium
& magnesium

Mg, Ca, K Requirements for Tree Growth



Sources: NADP, Weathers et al. 1988, Binkley et al. 1992

Strontium as a tracer for Base Cations

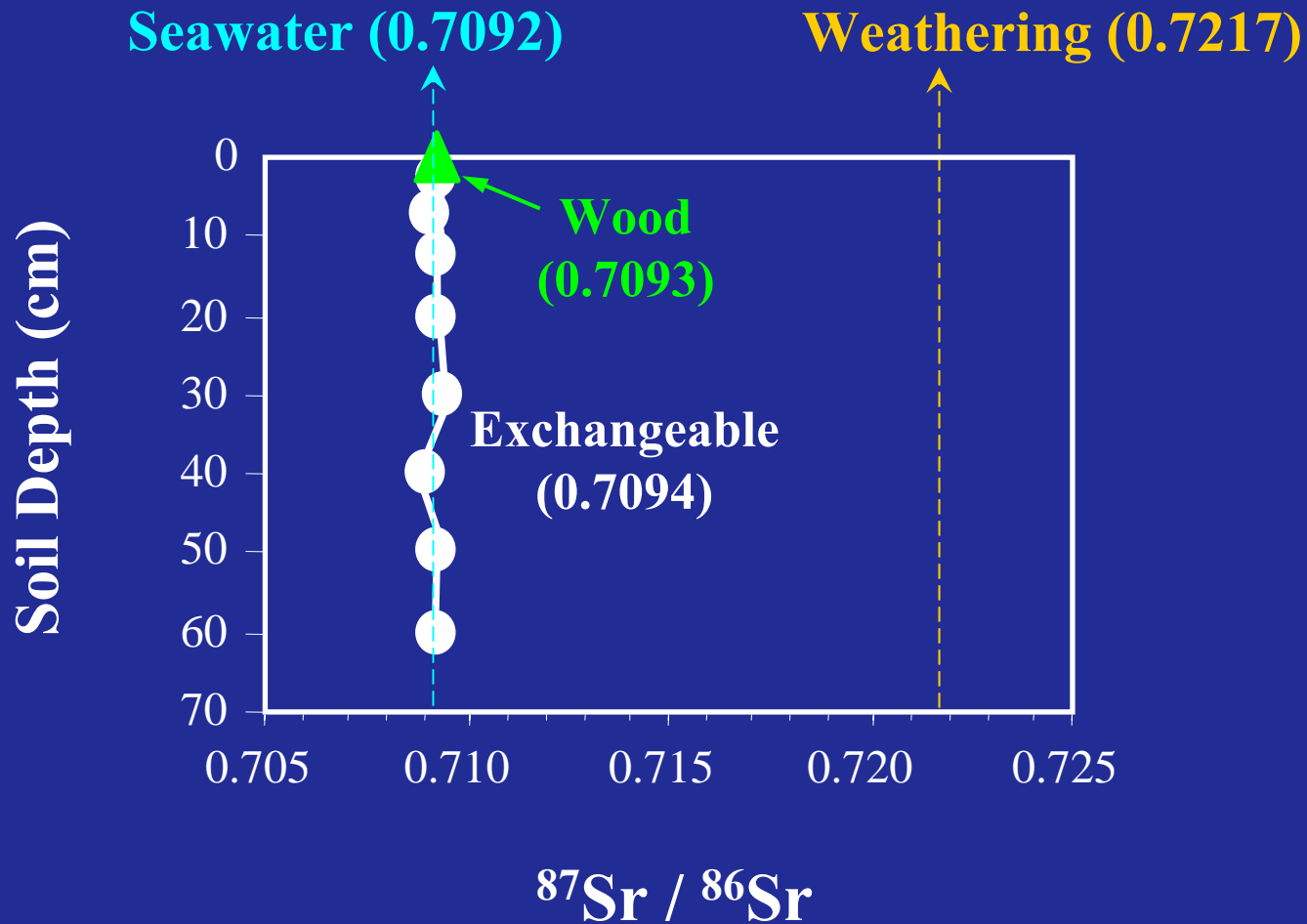
- Sr immediately below Ca on periodic table

Periodic Table of the Elements

H	He																
Li	Be	B	C	N	O	F	Ne										
Na	Mg	Al	Si	P	S	Cl	Ar										
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Uu	Uu	Uu						
Alkali Earth Metals		Lanthanide Series															
Alkaline Earth Metals		Actinide Series															
Transition Metals																	
Rare Earth Metals																	
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Halogens																	
Noble Gases																	

- Similar chemical and biological behavior to Calcium
- Natural $^{87}\text{Sr}/^{86}\text{Sr}$ variations reflect different sources (e.g. atmospheric inputs vs. bedrock weathering)

Strontium isotopes trace Base Cation sources



Base Cation Deficiencies in Forests:

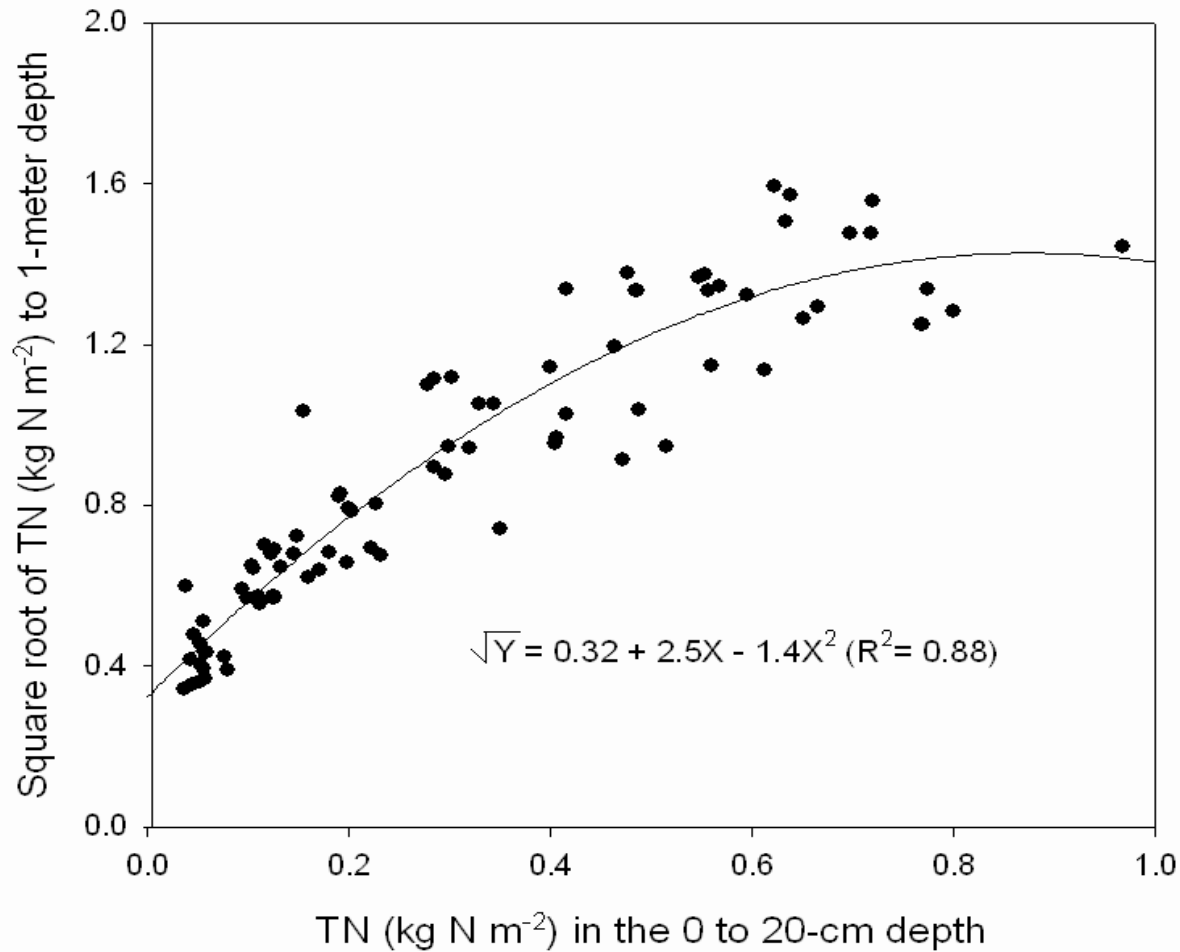
- Red spruce in north and southeastern USA
- Sugar maple in eastern USA and Canada
- Mixed northern hardwood forests in eastern USA
- Loblolly Pine in southern USA
- Norway spruce in Europe
- *Coastal Oregon Douglas-fir ???*

Wrap-up: Nutrition in N-Rich Sites

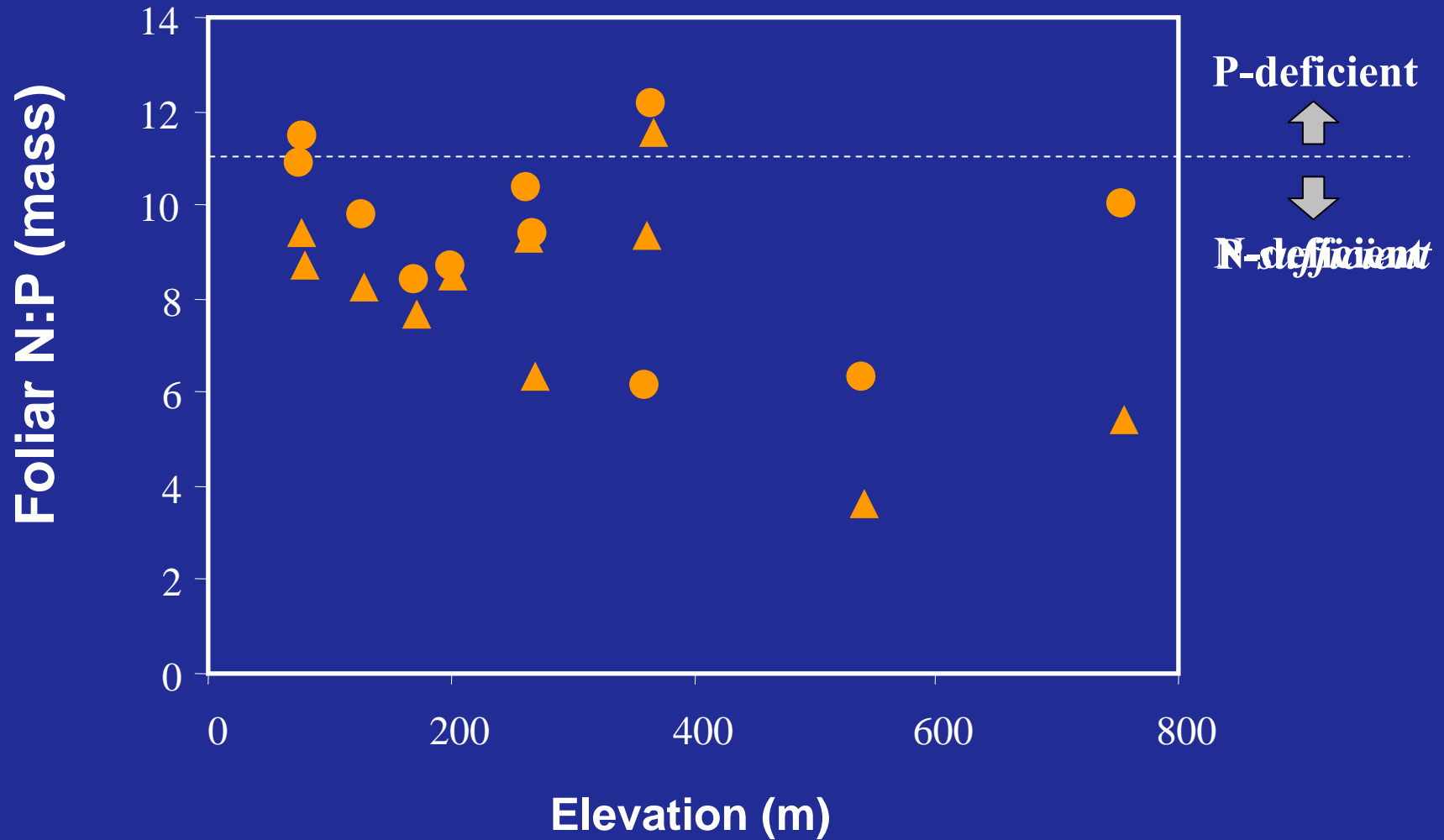
- Phosphorus - sticky, long-term depletion, organic matter
- Sulfur - abundant in precipitation, somewhat sticky
- Calcium - sparse in precipitation, readily leached
- Aluminum toxicity - ???, can disguise Ca deficiency
- Micro-nutrients - ???
- No deficiency - ???



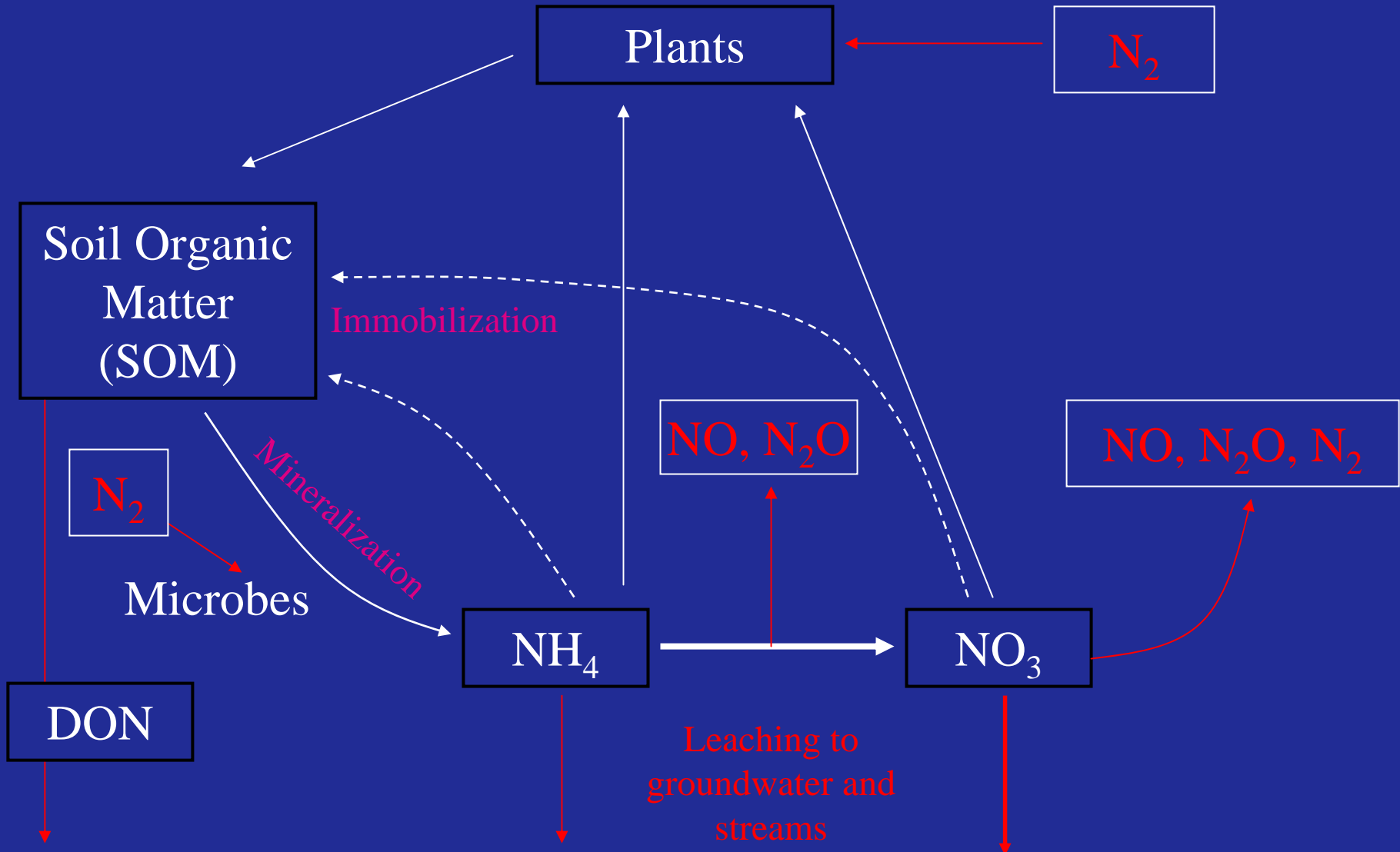
Surface soil nitrogen tracks whole-soil N



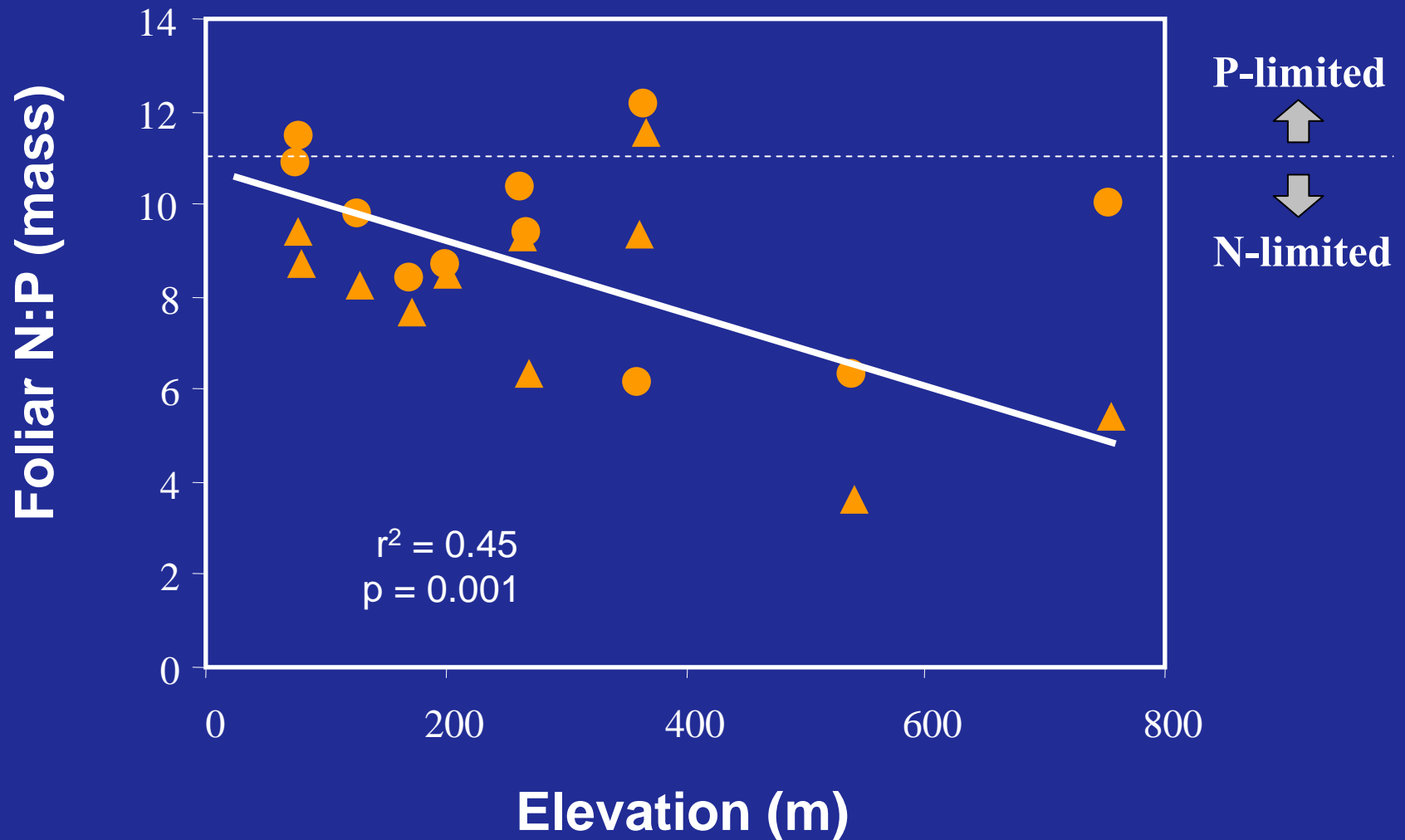
Foliar N:P ratios diagnose limitations



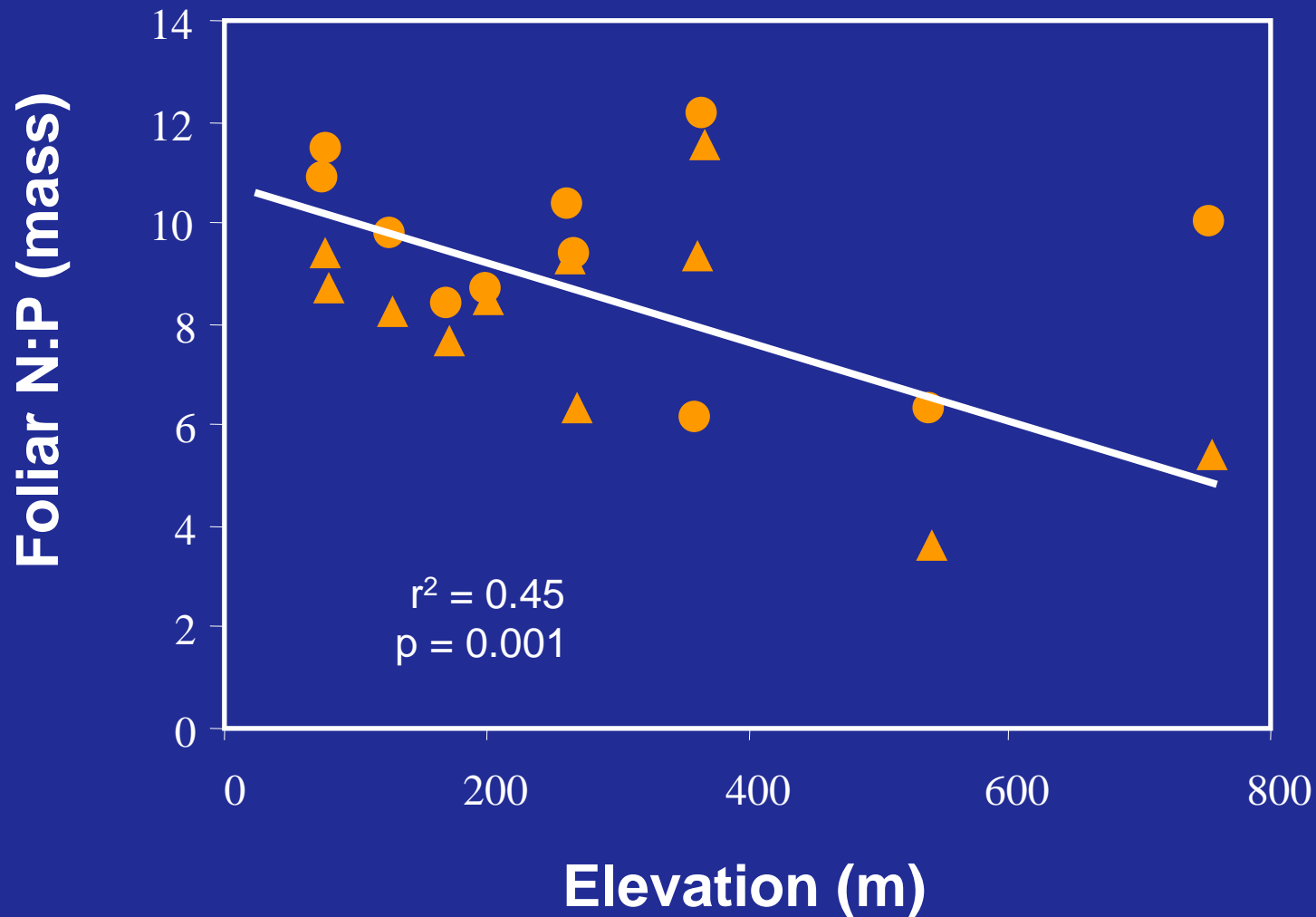
Nitrogen Cycle Dominates Forest Nutrition



Foliar N:P ratios in coastal Douglas-Fir



Foliar N:P ratios in coastal Douglas-Fir



Elements $> 0.1\%$ of plant dry mass are called macronutrients
 $< 0.1\%$ are micronutrients

Element	Principal function
carbon, hydrogen, oxygen	component of all organic molecules
nitrogen (N)	component of amino acids, proteins, chlorophyll, nucleic acids
phosphorus (P)	component of ATP, NADP, nucleic acids, phospholipids
potassium (K)	ion/ osmotic balance, pH regulation, regulation of guard cell turgor
calcium (Ca)	cell wall strengthening and functioning, ionic balance, membrane permeability
magnesium (Mg)	component of chlorophyll, enzyme activation
sulfur (S)	component of amino acids, proteins

Much interest in Sulfur

Strand, Youngberg, Turner, Gessel, Edmonds ...

Blake et al. 1988 – field experiment with N + S addition

”Because the field study does not provide a direct test of the N with S response ...”

S was added with P, Ca, K

Study stands responded to N alone – *they were N deficient*

Fertilization increased growth of low S stands

... decreased growth of high S stands