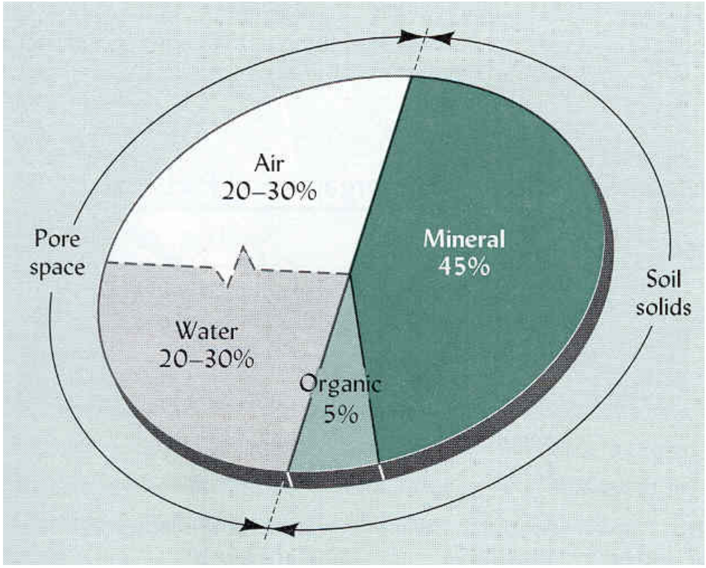
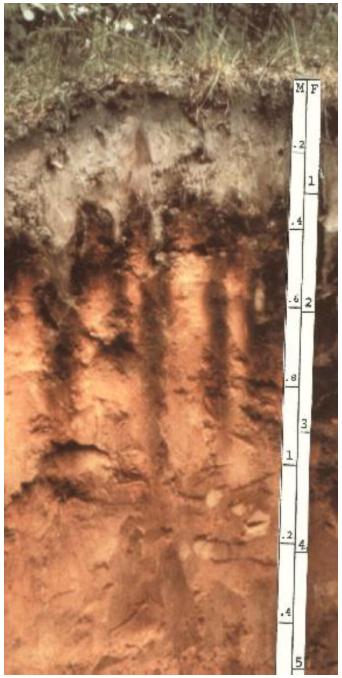
Unit 2

Soil Organic Matter



Histosol

Alfisol



Spodosol

OM ≈ OC x 1.7-2.0

(assumes 30% C)

(1.72 typically used as a conversion factor)

Nonliving (humus & detritus) and living (microbes, fauna, roots)

Forms of Soil Organic Matter:

- dissolved (soil solution): DOM
- discrete solid phase: SOM (colloids)
- complexed with soil minerals

Soil Organic Matter

(CHONPS)

Important Functions:

Structure - maintenance of good soil pore structure and clay aggregation

Climate - temperature and moisture

Water - increased water retention and improved water entry

Nutrients - retention of nutrients: cations (by cation exchange, complexation, chelation) and anions (by ligand exchange, metal bridges)

- release of N, P, S and trace elements by mineralization
- retention/release of potentially toxic organics and inorganics

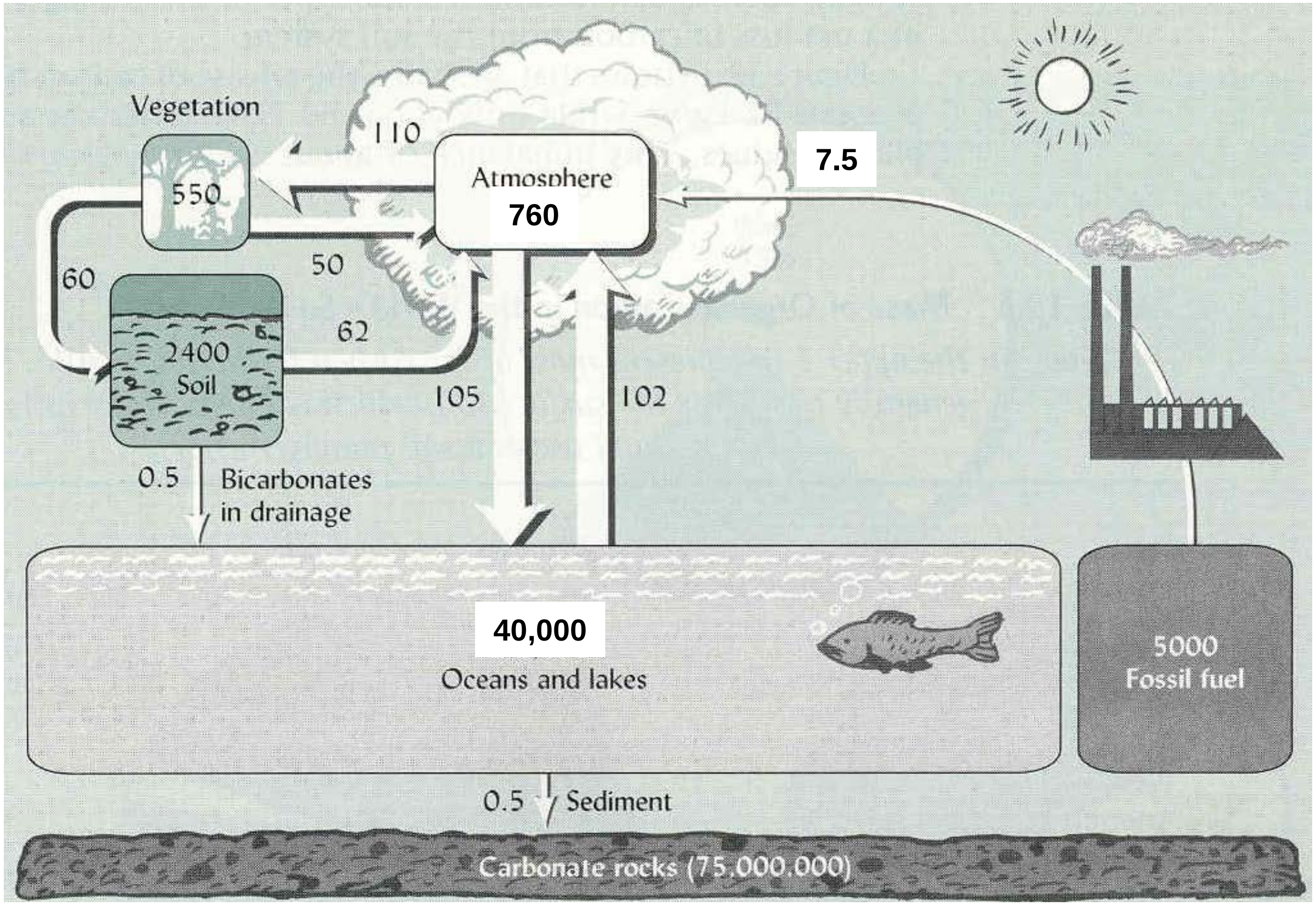
Earth Pools (and Cycling) of **Organic Carbon**

The Global Carbon Cycle

Critical Zone in the Environmental Interface

Global SOC pool ≈ Vegetation pool x 4

Global SOC pool ≈ Atmospheric pool x 3



Flux imbalances?

Net:

219.5 Pg/yr enters atm

while

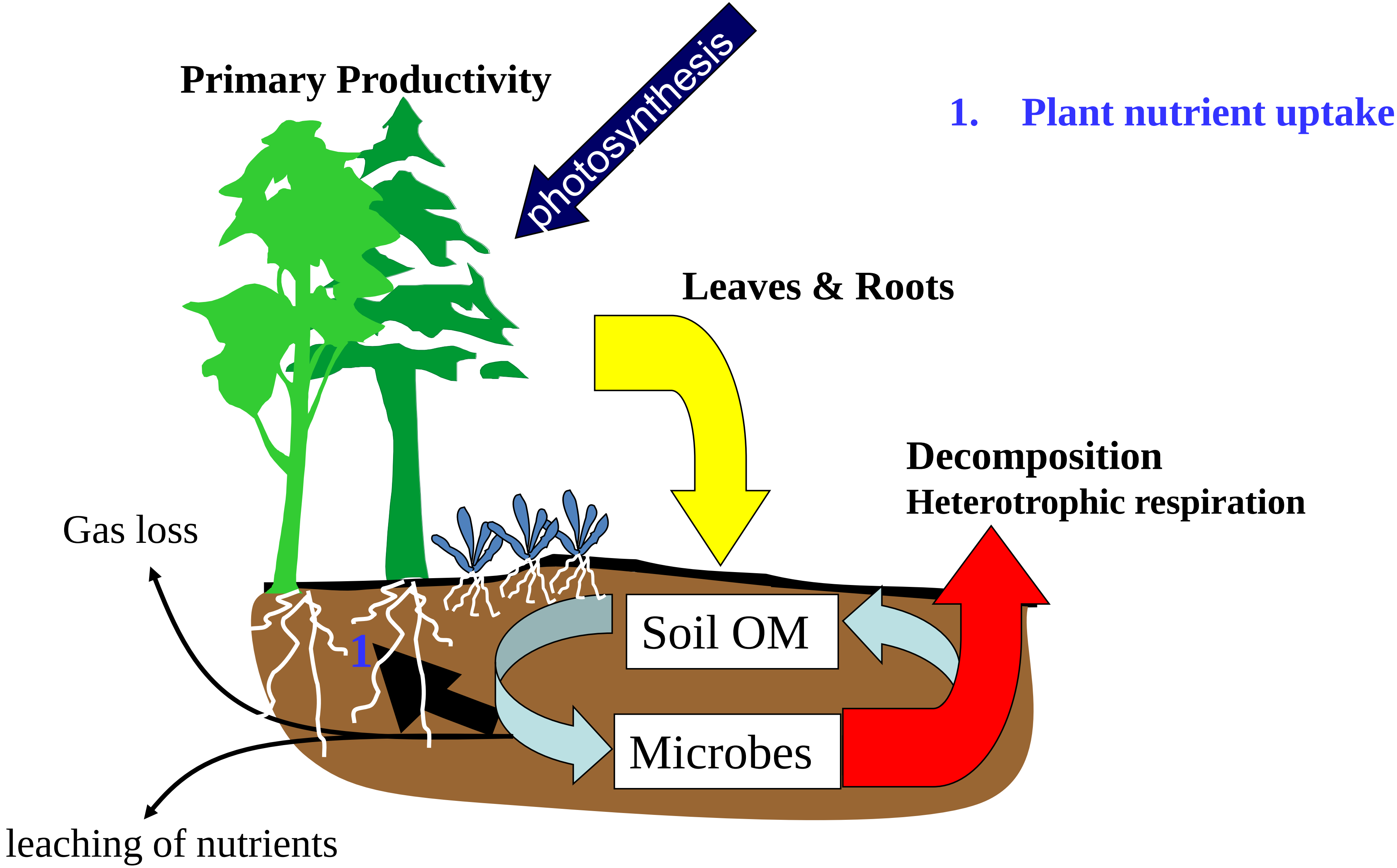
215 Pg/yr removed from atm

1576 Pg of SOC (depth of 1 m)
1738 Pg of Inorganic C
} **3314 Pg of C**

Pools = units of 10^{15} g Carbon (peta = 10^{15})

Fluxes = units of 10^{15} g Carbon / year

OM pathways in an ecosystem



Litter and microbes: precursors to and/or components of SOM?

Terrestrial Organic Carbon: Stocks by Ecosystem Type

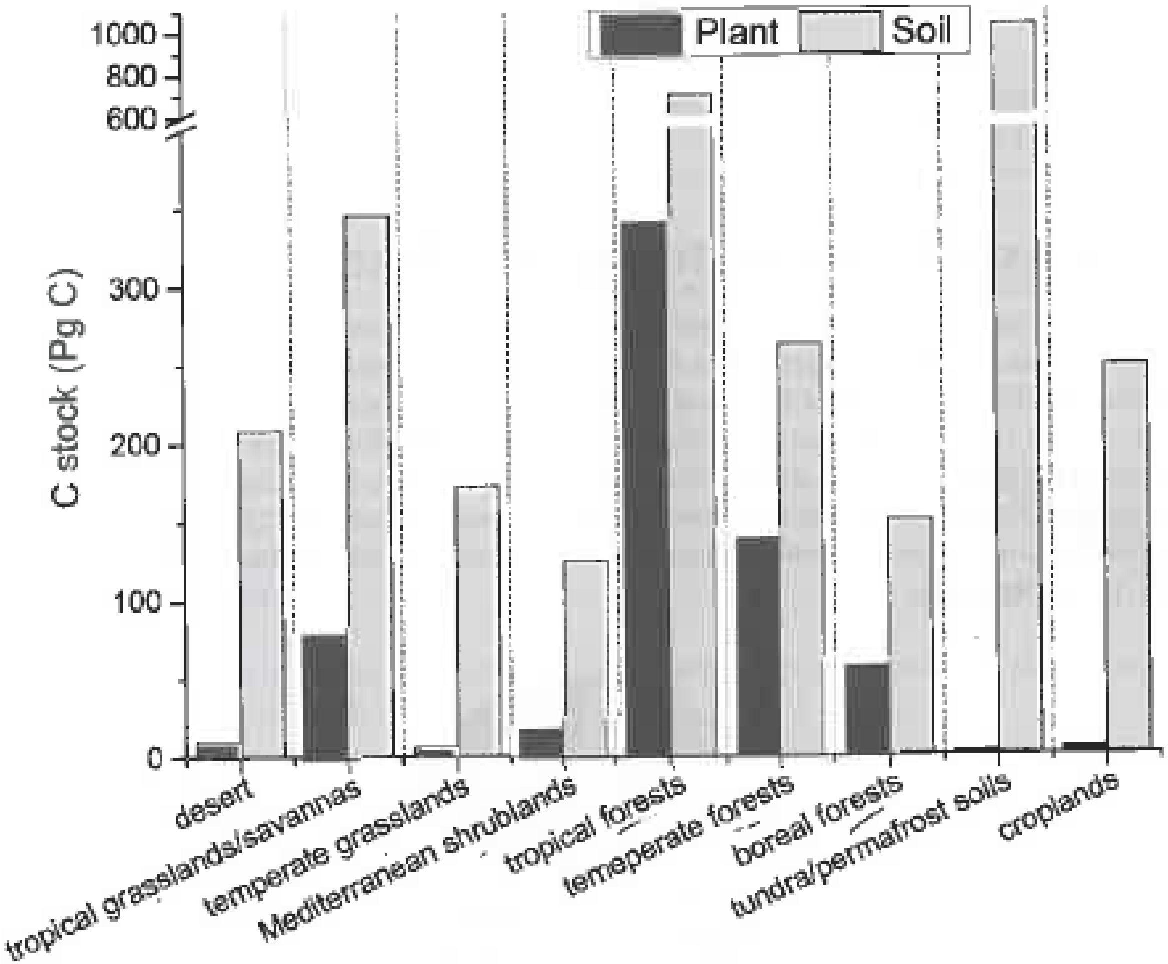


Figure 8.3 Terrestrial organic C stocks by ecosystem type. Soil carbon estimates are for 0–3 m depth. Sum of the plant C in the figure is 654 Pg, and the sum of soil organic C in the figure is 3225 Pg (including tundra/permafrost soils). Data are reported in Sabine, C.L.,M. Heimann, P. Artaxo, D.C.E. Bakker, C.T.A. Chen, C.B. Field and N. Gruber, 2004, Current status and past trends of the global carbon cycle, *Global Carbon Cycle: Integrating Humans, Climate, and the Natural World*, C.B. Field and M.R. Raupach, eds., Island Press, Washington, District of Columbia, 17–44. Tundra/permafrost soil C estimate is from Tarnocai, C., J.G. Canadell, E.A.G. Schuur, P. Kuhry, G. Mazhitova, and S. Zimov, 2009, Soil organic carbon pools in the northern circumpolar permafrost region, *Global Biogeochemical Cycles* 23.

Carbon is not equally distributed among all types of soils

Organic Carbon Content and Global Organic Carbon Mass of Surface Soils (A and B Horizons)[a]

Soil Order	Mean ± Standard Error[b]	Median	Range	Global Mass (Pg)
	g C kg^{-1}			
Alfisols (292)[c]	5.80 ± 0.39	3.8	0.2–50.0	127
Andisols (36)	57.1 ± 10.5	38.3	0.9–308	78
Aridisols (36)	6.67 ± 0.92	5.4	1.6–33.1	110
Entisols (53)	14.4 ± 2.38	6.6	0.3–94.2	148
Histosols (310)[d]	419 ± 7.7	—	306–724	357
Inceptisols (362)	18.8 ± 1.09	10.5	0.3–113.7	352
Mollisols (239)	12.2 ± 0.71	8.4	0.4–54.5	72
Oxisols (231)	13.4 ± 1.03	7.8	0.6–117.3	119
Spodosols (24)	57.6 ± 15.0	27.9	0.6–331.4	71
Ultisols (218)	8.64 ± 0.75	4.6	0.3–72.0	105
Vertisols (81)	12.4 ± 1.04	8.4	1.5–46.7	19

~50% of the total C (Histosols + Inceptisols)

1558 Pg

P = peta = 10^{15} g Carbon

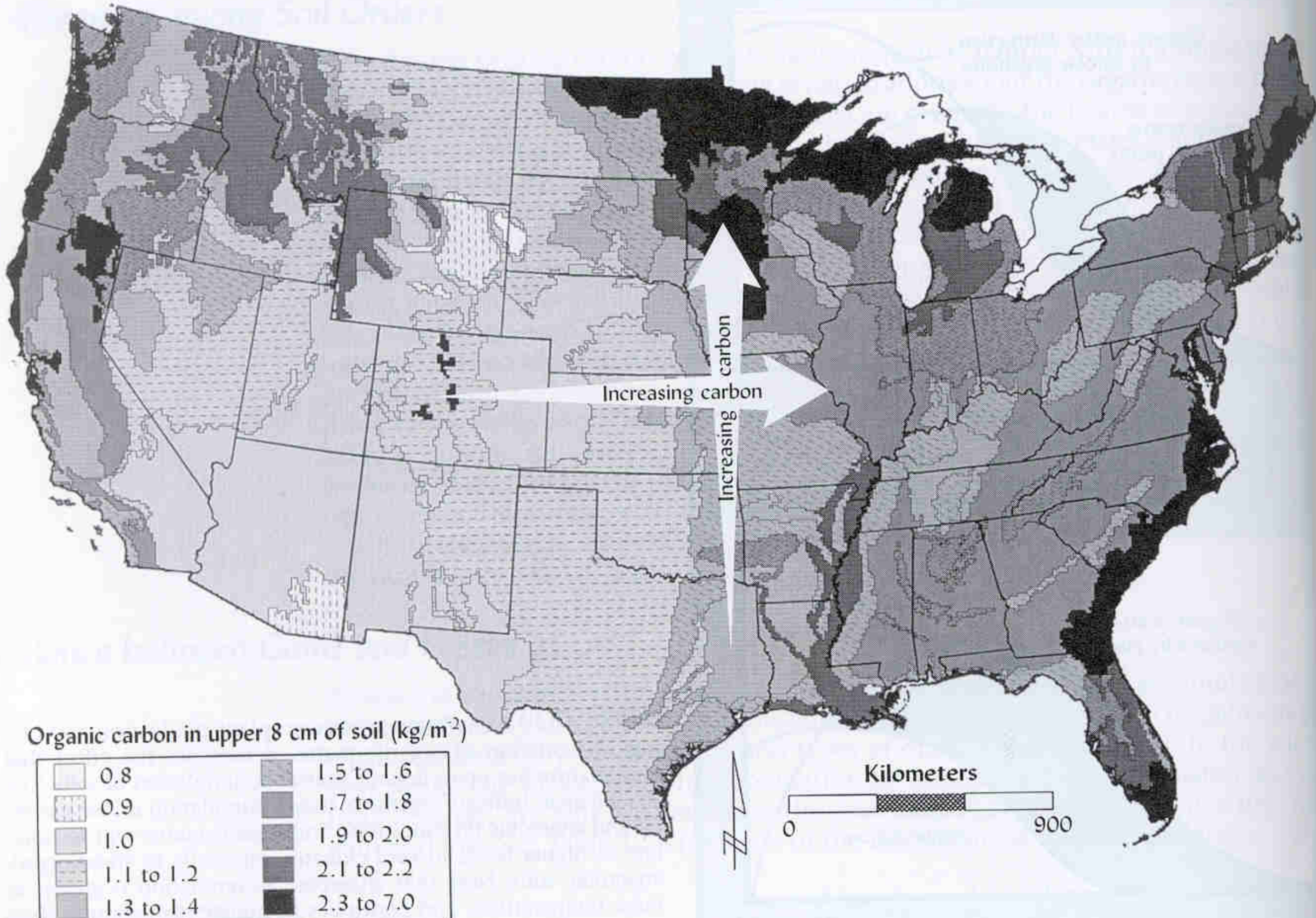
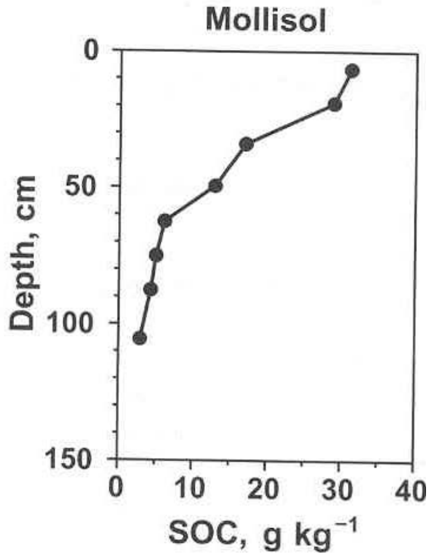
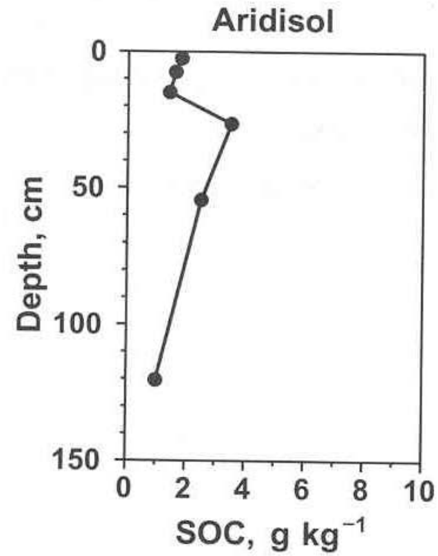
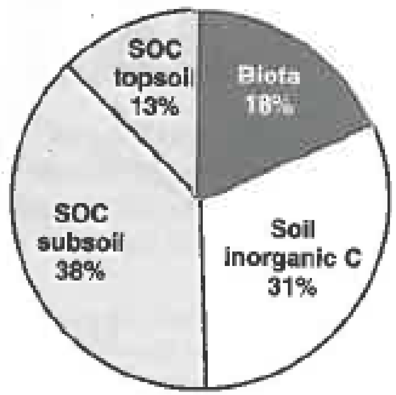


FIGURE 12.21 Influence of mean annual temperature and precipitation on organic matter levels in soils and on the difficulty of sustaining the soil resource base. The large white arrows on the map indicate that in the North American Great Plains region, soil organic matter increases with cooler temperatures going north, and with higher rainfall going east, provided that the soils compared are similar in texture, type of vegetation, drainage, and all other aspects except temperature and rainfall. These trends can be further generalized for global environments. [Kern (1994); Map courtesy of J. Kern, U.S. Environmental Protection Agency.]

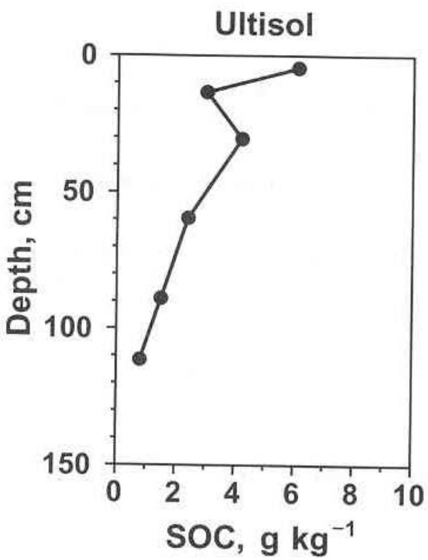
Distribution of Soil Organic Carbon as a Function of Depth

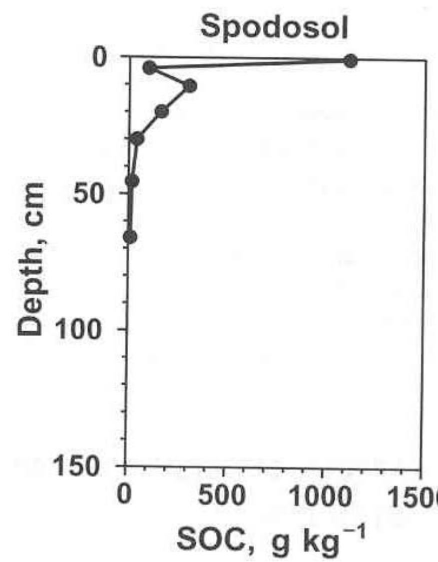




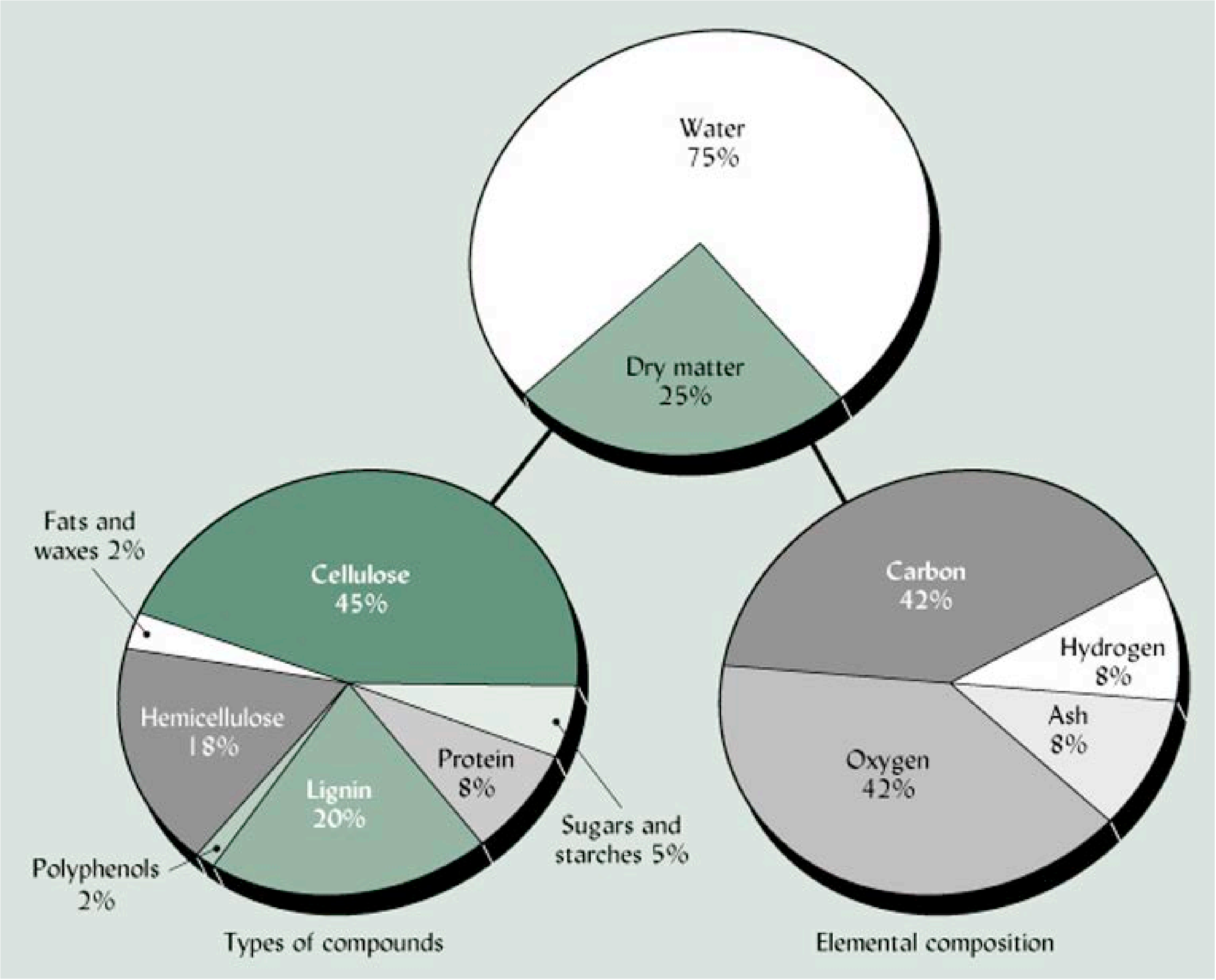


Global distribution of terrestrial C





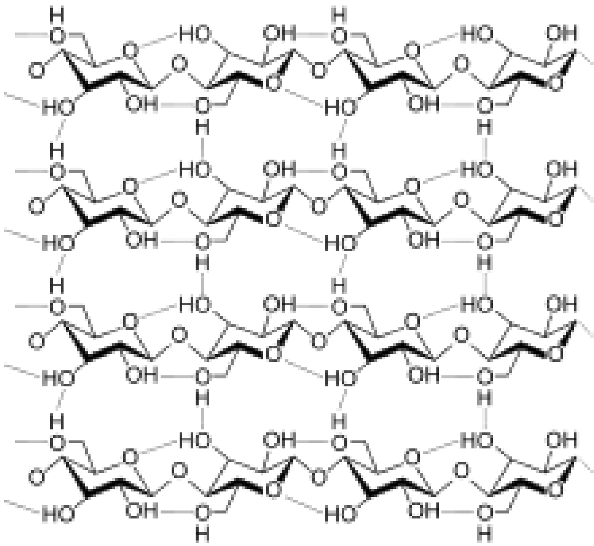
What is organic matter?



Organic molecules in Soils

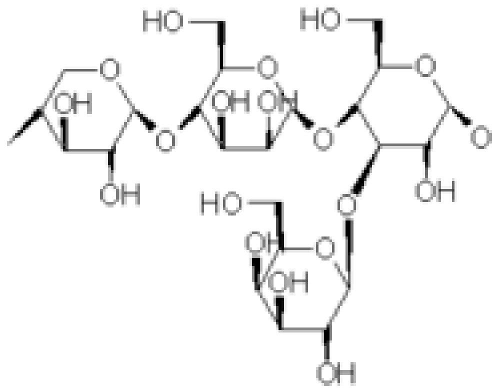
Cellulose (polysaccharide)

7,000-15,000 glucose molecules per polymer;
unbranched polymer



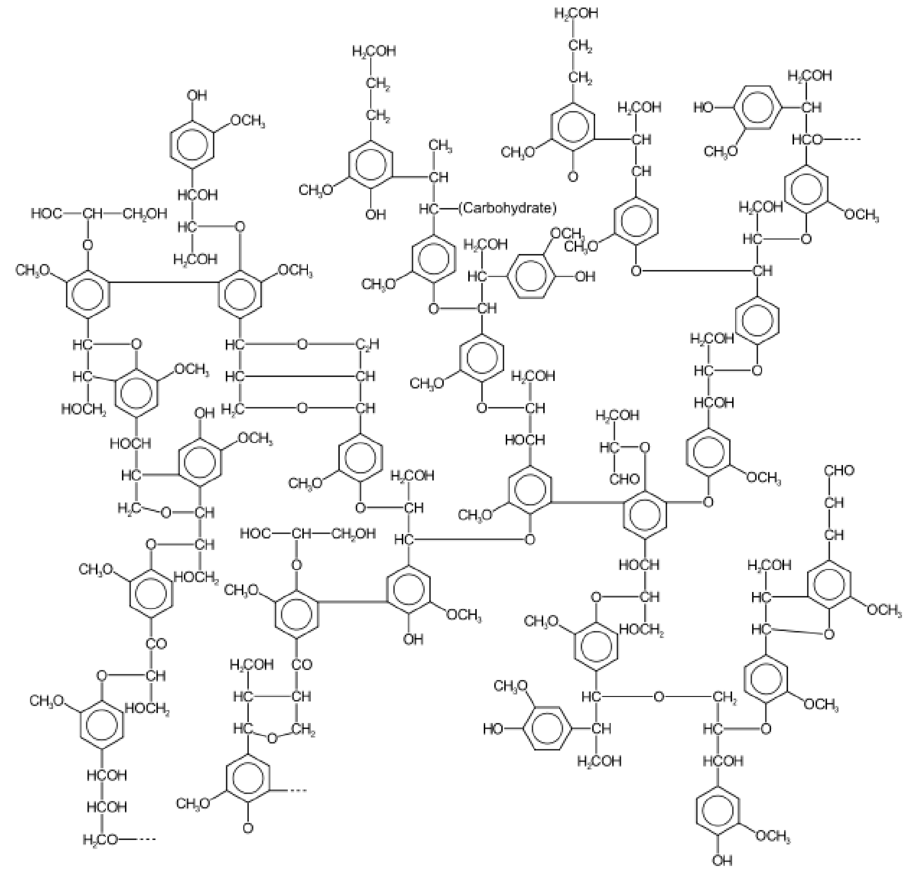
Hemicellulose (polysaccharide)

500-3,000 sugar units per polymer;
branched polymer



Lignin

a very stable component of plant cell walls

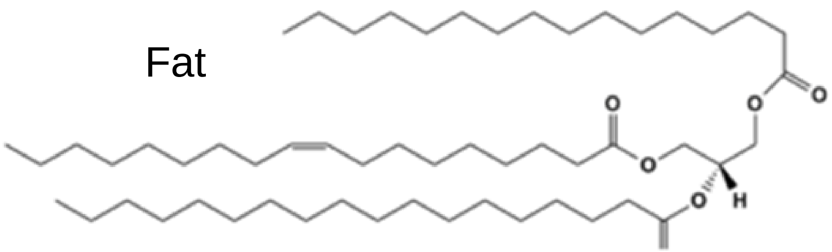


Organic molecules in Soils

Lipids

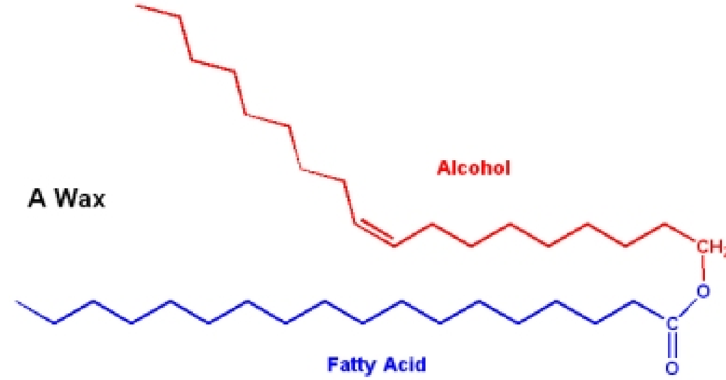
some are structural components of cell membranes (plants, microbes); store energy

Fat

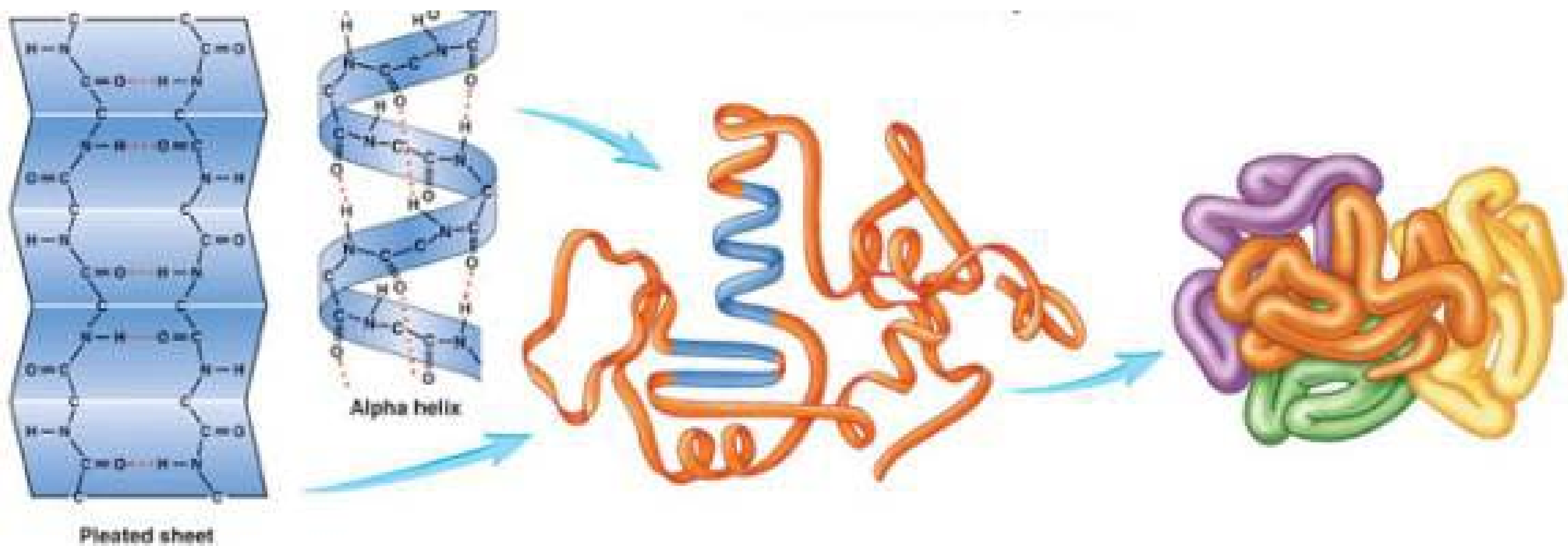


A triglyceride

A Wax



Proteins



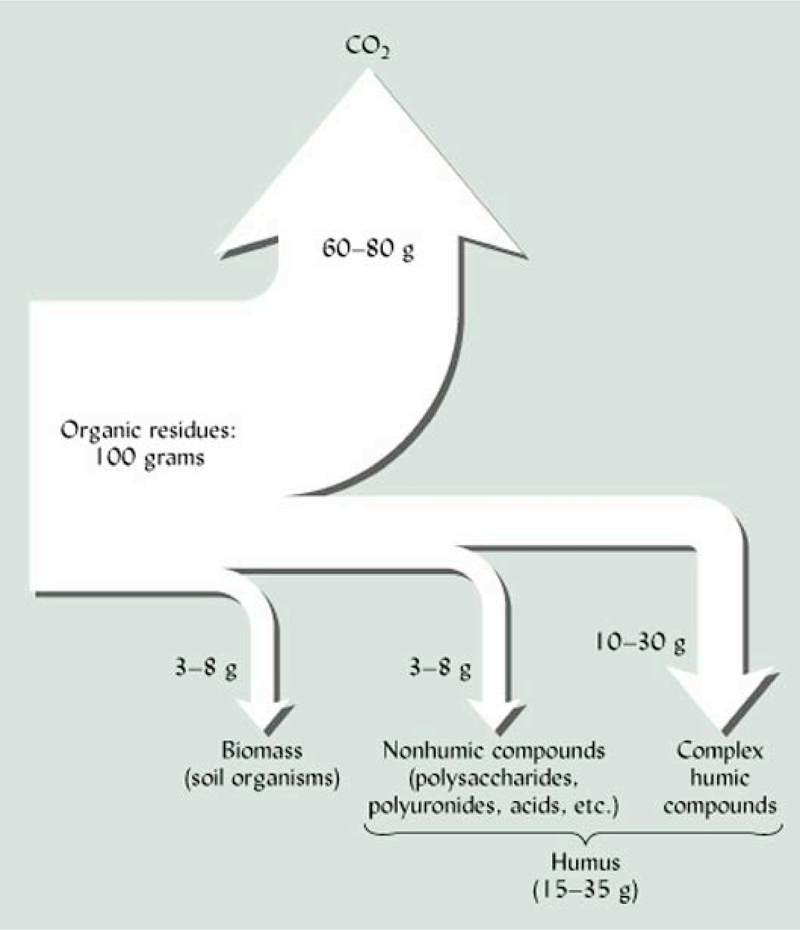
Relative composition of organic molecules in plants and microbes

Biogeochemistry (2007) 85:9–24

Table 1 Relative composition of vascular plants, algae, bacteria, and fungi, compiled using data from Knicker (2004) and White (1997)

	Vascular plants	Algae	Bacteria	Fungi
	% Dry matter			
Lignin	5–30			
Cellulose	15–60			
Hemicellulose	10–30			
N-containing compounds	2–15	24–50	50–60	14–52
Lipids		2–10	10–35	1–42
Carbohydrates		40	4–32	8–60
	Ratio			
C:N ratio	20–50 (tree leaves) 25–80 (herbaceous plants)	6	5–8	≈10

Decomposition of organic residues



$$C_6H_{12}O_6 + 6O_2 \dashrightarrow 6CO_2 + 6H_2O$$

1. **CONSUMES OXYGEN (O_2)**
2. **PRODUCES CARBON DIOXIDE (CO_2)**

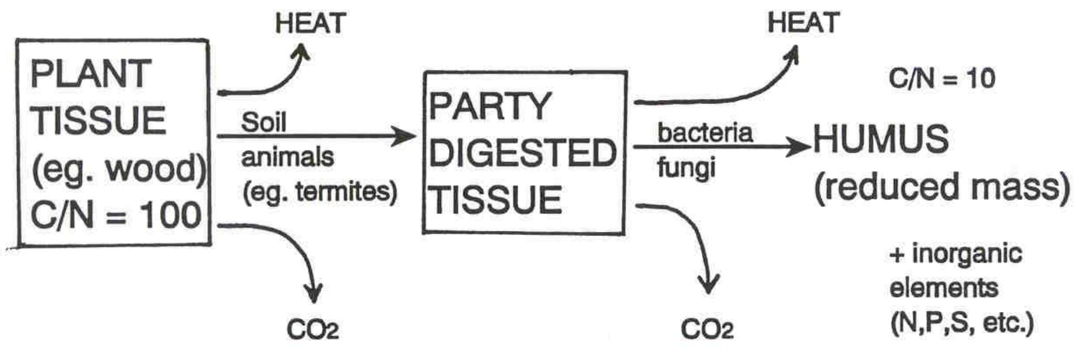
Effects of Respiration on Soil:

1. Raises CO_2 in soil air by 10-1000x
2. Lowers soil pH (carbonic acid)
3. Lowers O_2 level; potential for anoxia

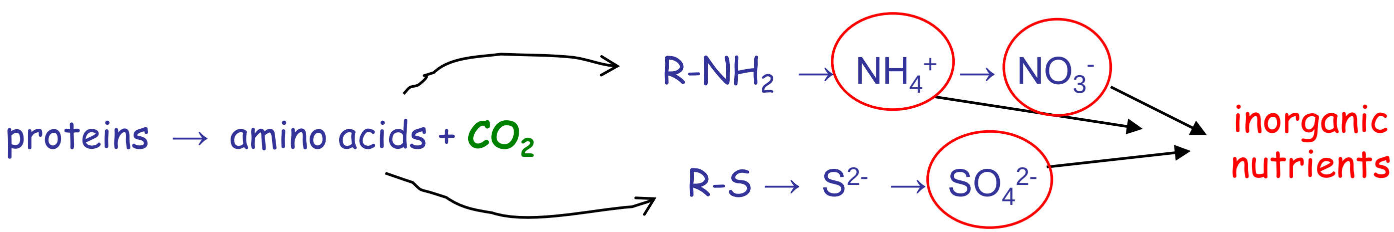
Note: low CUE (Carbon Use Efficiency)

Decomposition: The breakdown of matter by bacteria and fungi. It changes the chemical composition and physical appearance of the materials. It is the process by which carbon is released from decaying biological matter.

Decomposition of organic residues ⟶ Formation of SOM



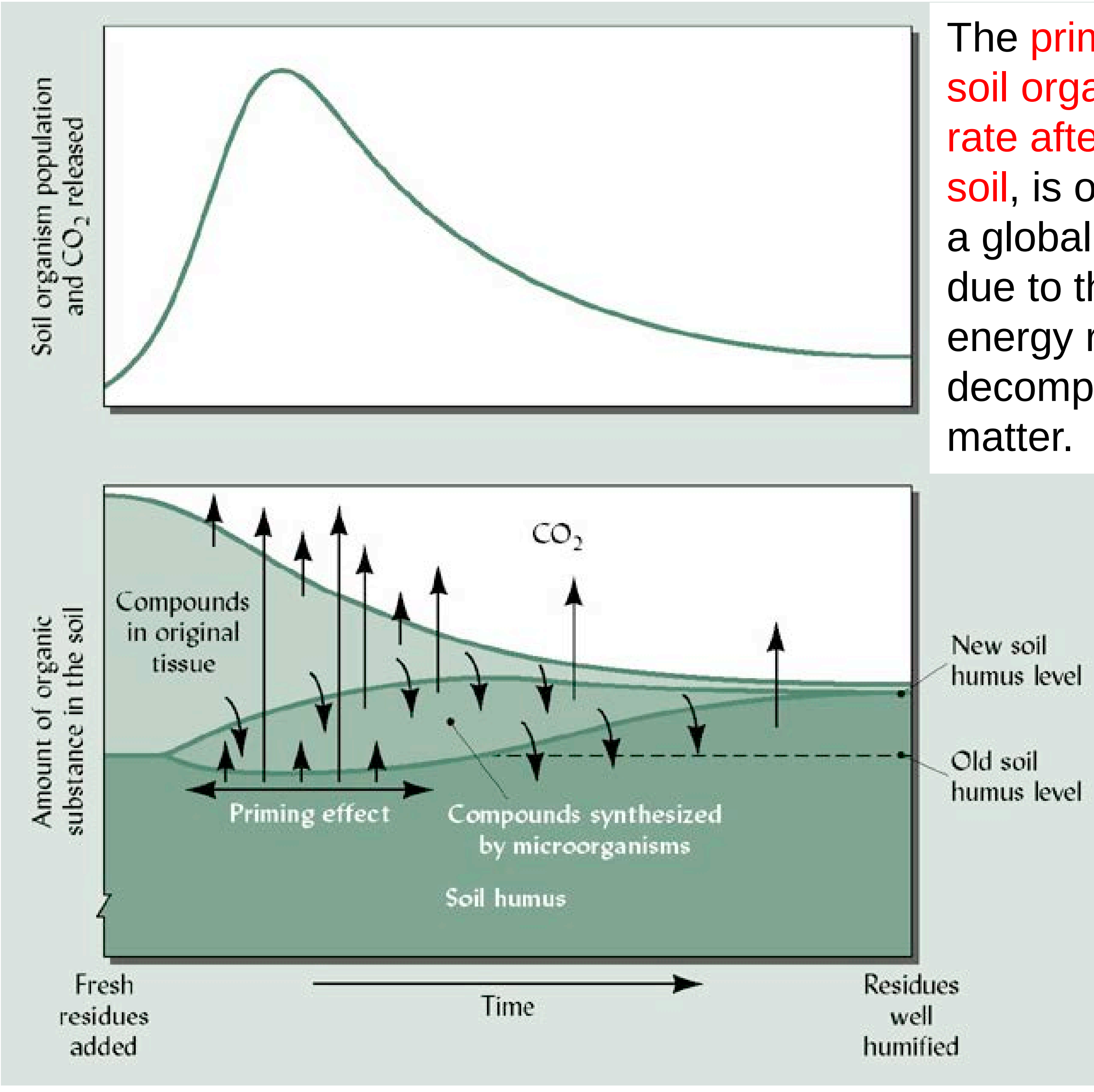
"humification", by definition, "the (abiotic) polymerization into new covalently bonded carbon compounds in soils is controversial"



Mineralization – refers to the overall process that releases elements from organic compounds to produce inorganic (mineral) forms

Immobilization - the conversion of an element from an inorganic state to an organic state (biomass)

Addition of fresh plant residues to soil



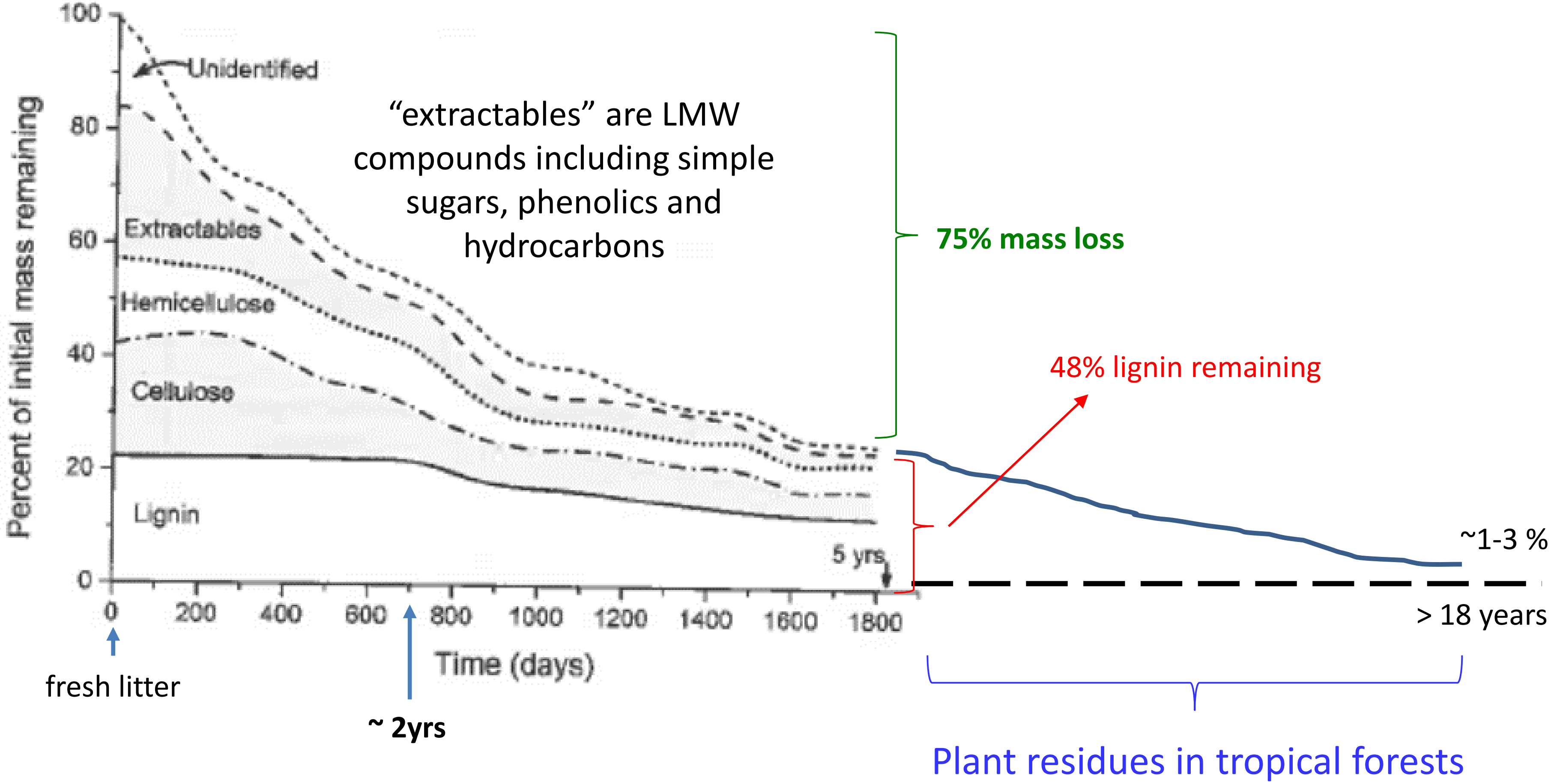
The priming effect, i.e. the increase in soil organic matter decomposition rate after fresh organic matter input to soil, is often supposed to result from a global increase in microbial activity due to the higher availability of energy released from the decomposition of fresh organic matter.

Quality of fresh organic matter affects priming of soil organic matter and substrate utilization patterns of microbes

Consideration of microbial demands for nutrients and fresh OM supply simultaneously is essential to understand the underlying mechanisms of PE

Decomposition of plant residues

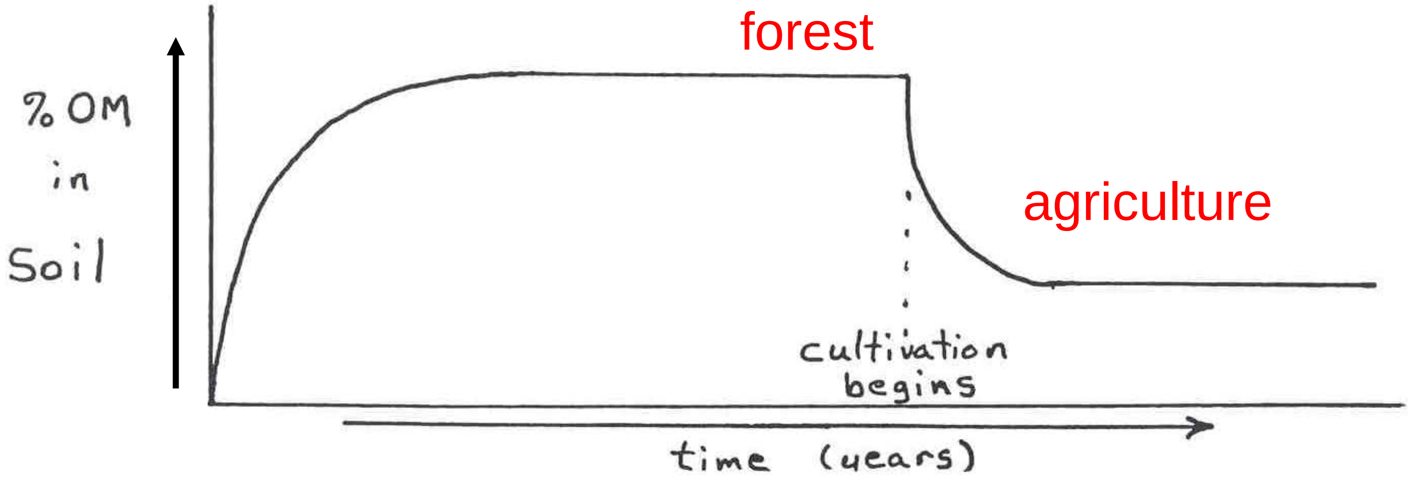
biomolecules from pine needle litter



Factors controlling the rate of (S)OM decay

Ecosystem properties (biotic/abiotic)

Placement = Location; Size and Surface Area; C:N Ratio; Litter Quality



Globally, surface soils have lost 25-50 % of their carbon over the last 100-125 years during the period of intensive cultivation.

This carbon is now in the atmosphere as carbon dioxide.

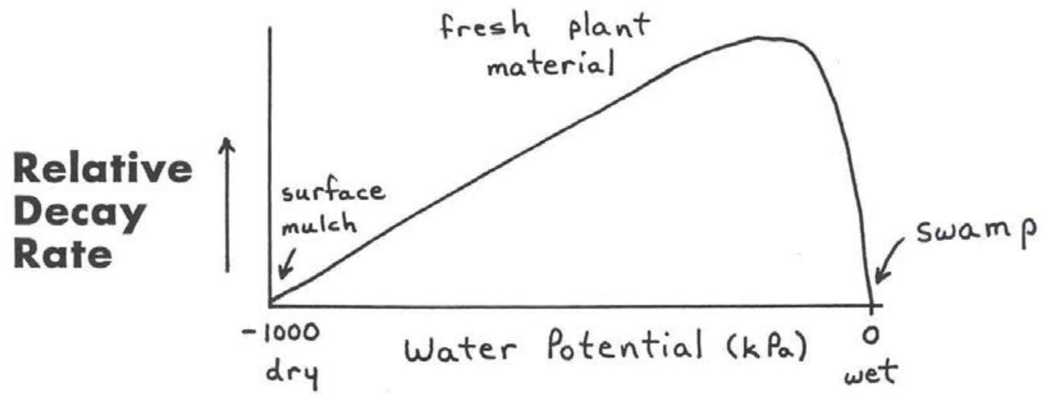
More effective soil management could reverse some of this loss [by altering microbial processes] to restore some of this soil carbon.

Turn the table: Organic Matter Persists in Soils

$SOM \xrightarrow{\text{turnover time}} CO_2$

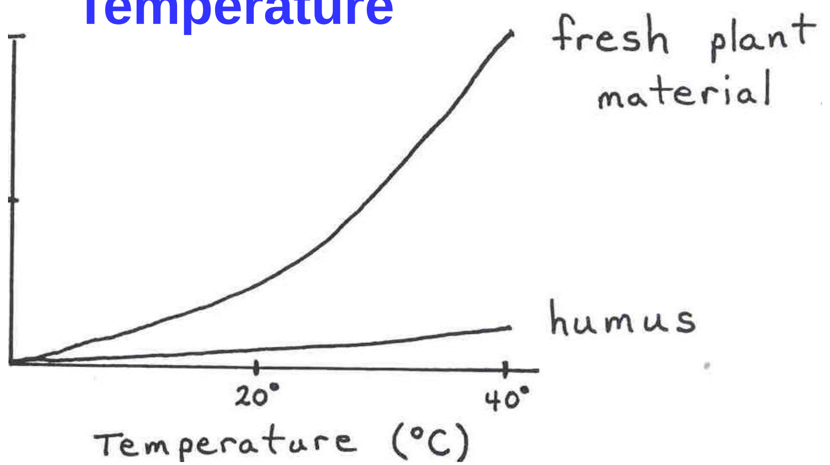
OM persistence: varies with climate and soil properties

Water



Decay fastest in moist soil
Slow in dry or waterlogged soil

Temperature



Result: cool climates produce soils with high organic matter

Chemical Factors ~ factors which might inhibit microbes

- **extremes of pH (<4.5, >9) inhibit decay**
- **very high salinity inhibits decay**
- **nutrient deficiencies (usually N) inhibit decay.**

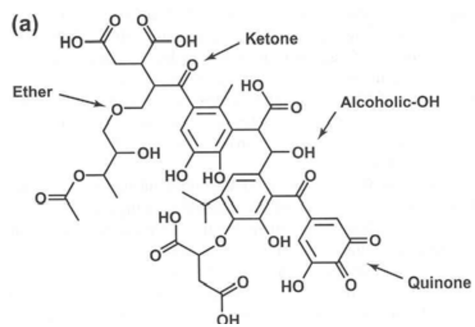
Turn the table: Organic Matter Persists in Soils

$$SOM \xrightarrow{\text{turnover time}} CO_2$$

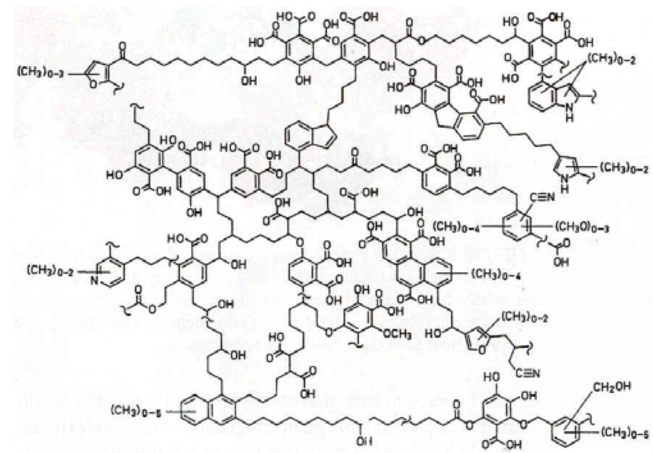
A closer look:

1. Inherent chemical recalcitrance

small molecule



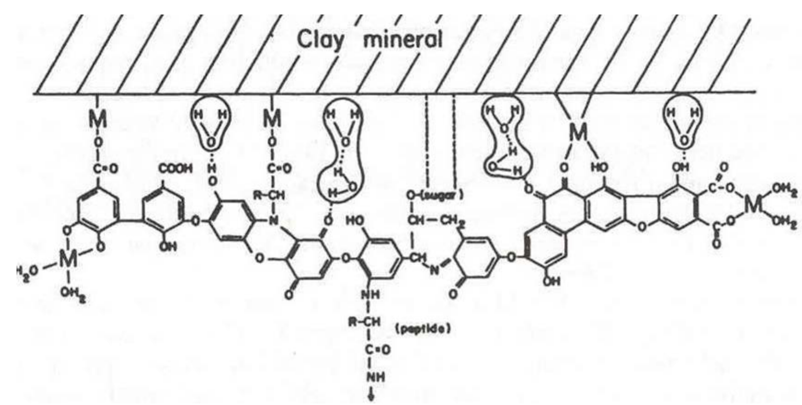
large molecule



2. Chemical stabilization via bonding

polycationic metals (Al^{3+}, Fe^{3+}, Cu^{2+})

to surfaces (clays, oxides)

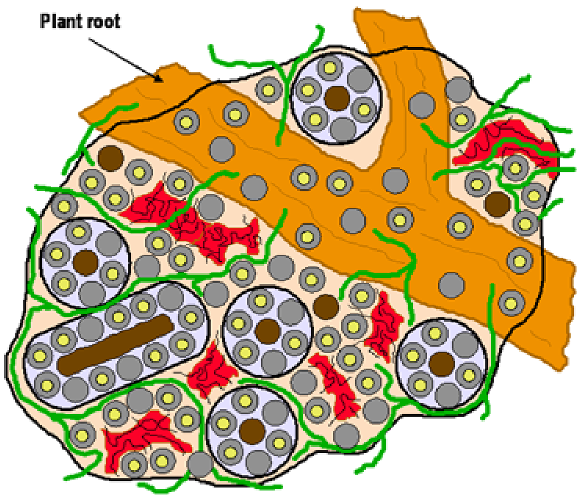


Turn the table: Organic Matter Persists in Soils

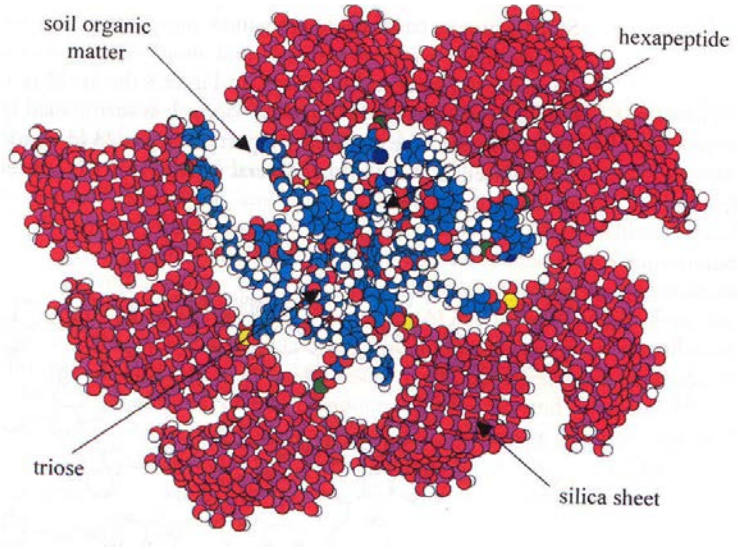
3. Physical occlusion ≈ Location

within aggregates

(macro at 250-2000 µm, micro at 53-250 µm)



within mineral particles

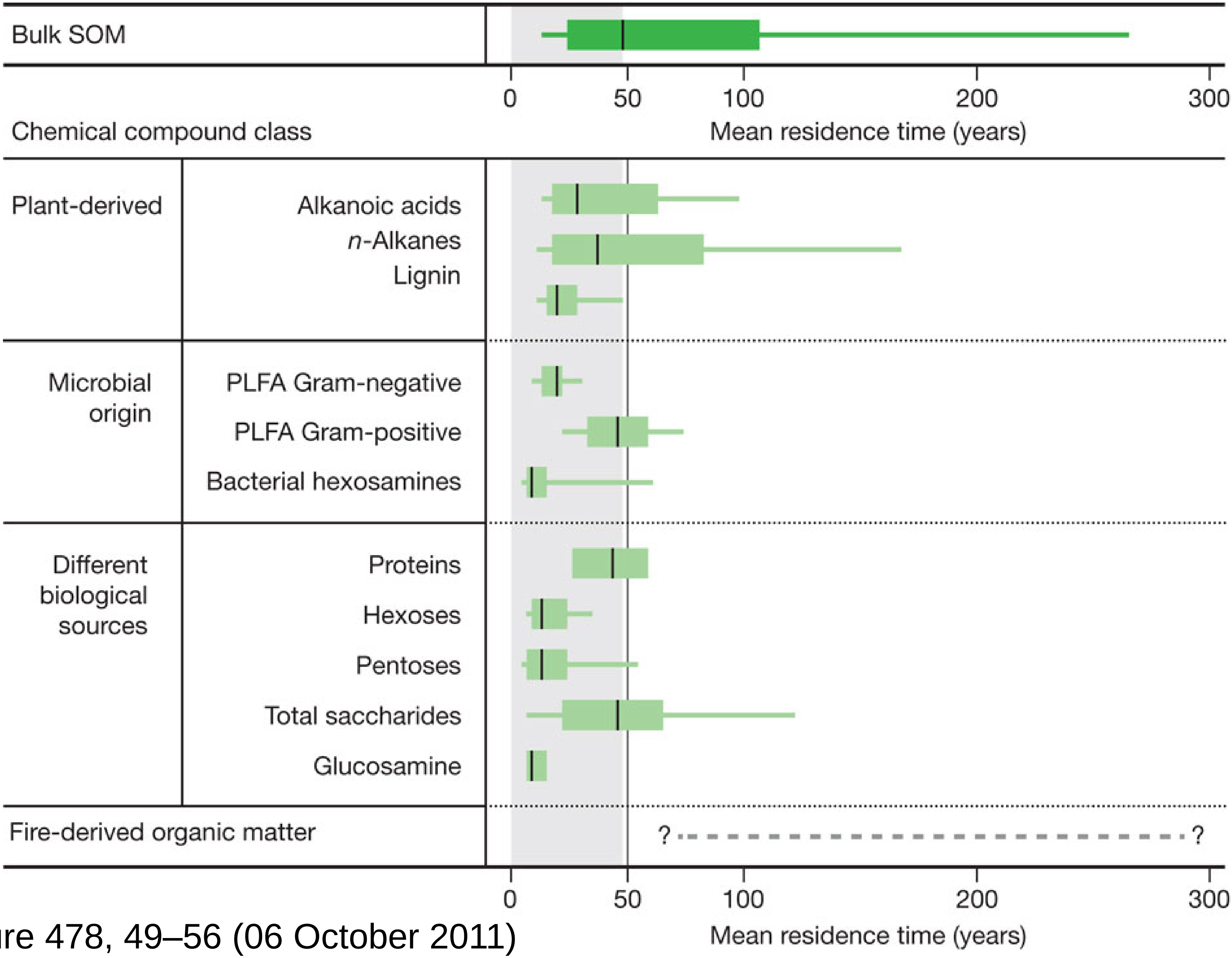


accessibility to decomposition

Minerals physically isolate SOM from microbes and inhibit degradation

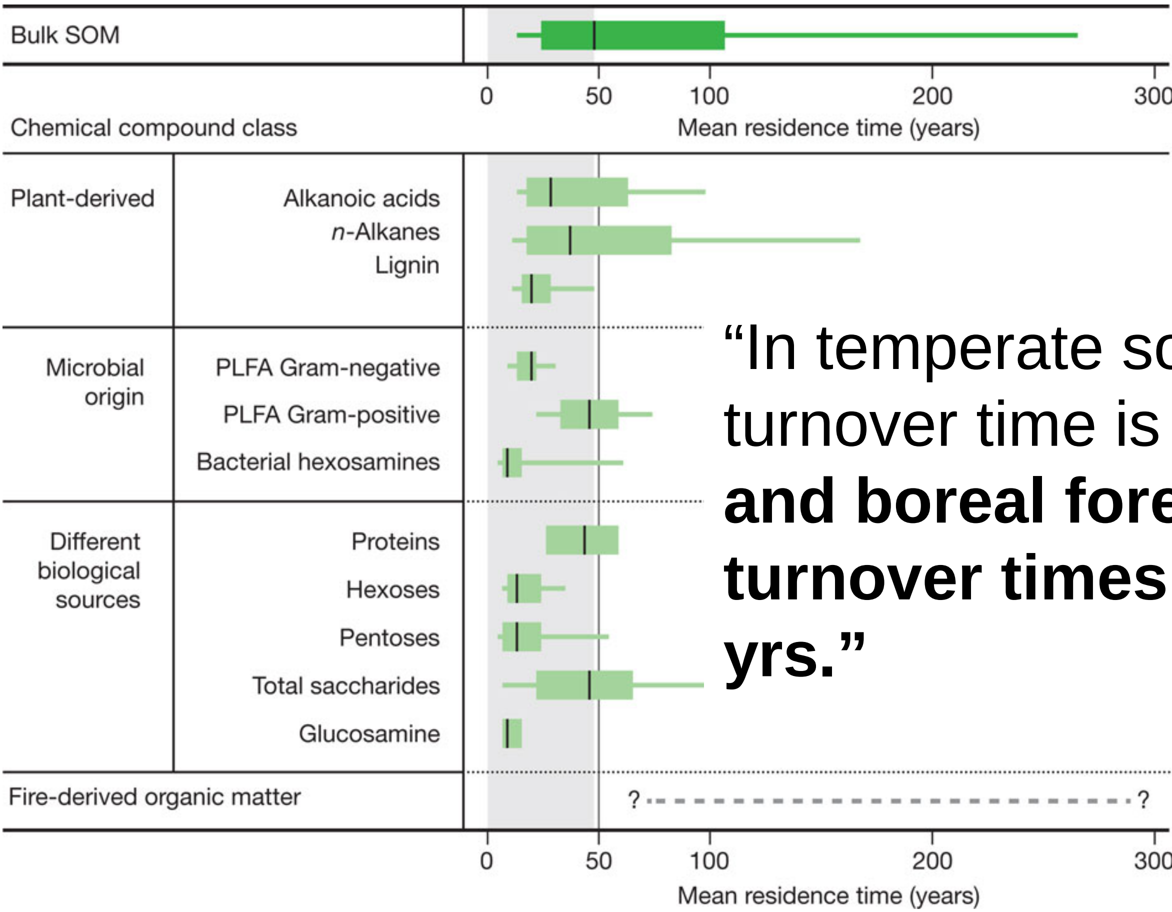
There might be limits on O_2 diffusion needed for degradation

Observed mean residence times for several organic compounds



Nature 478, 49–56 (06 October 2011)

Observed mean residence times for several organic compounds



"In temperate soils, the average turnover time is 50 yrs, but **in tropical and boreal forests the average turnover times are greater than 1000 yrs."**

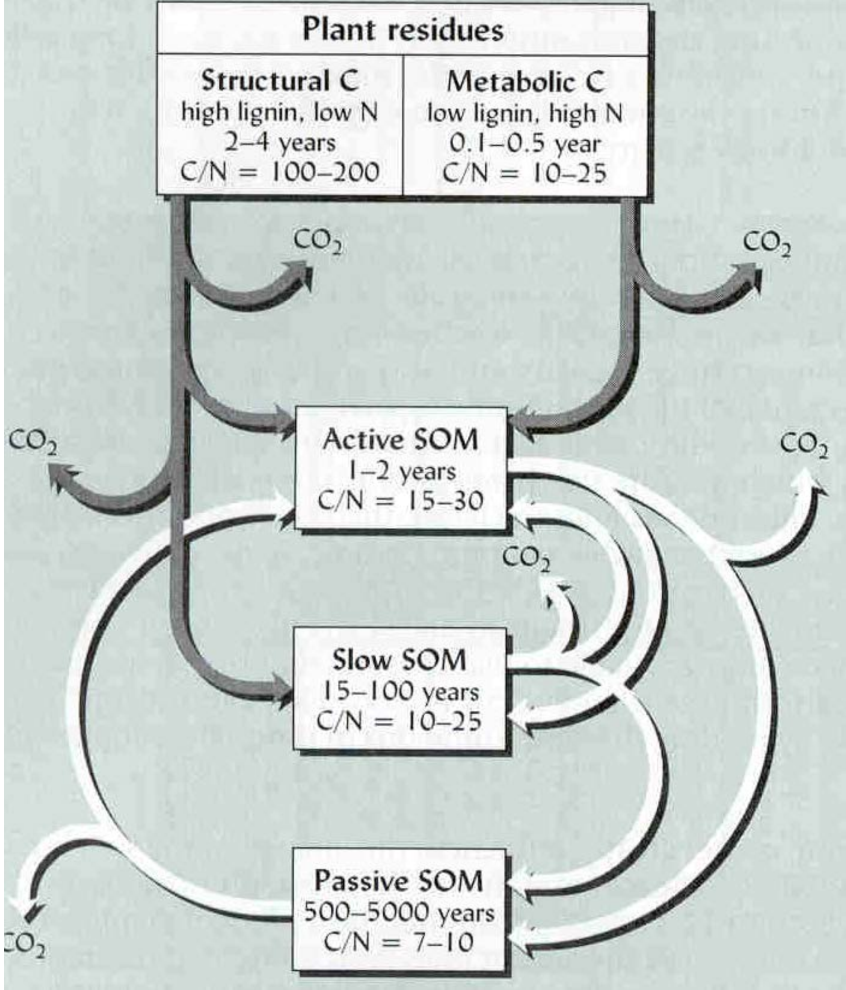
What is it? "ecosystem properties"

Inherent chemical recalcitrance

Chemical stabilization via bonding

Physical occlusion

Climate and soil properties: water content, temperature, pH, nutrient deficiencies, and mineral composition of the soil



SOM "pools"

Active: live microbes and their by-products (0.5 to 5 year turnover)

Slow: physically and chemically protected (10 to 50 year turnover)

Passive: physically protected or chemically resistant (800 to 1200 year turnover)

SOM pools are the basis for the **CENTURY Ecosystem Model**

-- based on turnover rates of SOM pools -- evaluate the effects of environmental change

-- evaluate changes due to management practices

Current developments: incorporation of microbial processes into models to allow scientists to evaluate the soil management practices that can restore soil carbon globally

Soil Organic Matter Management

Purposes:

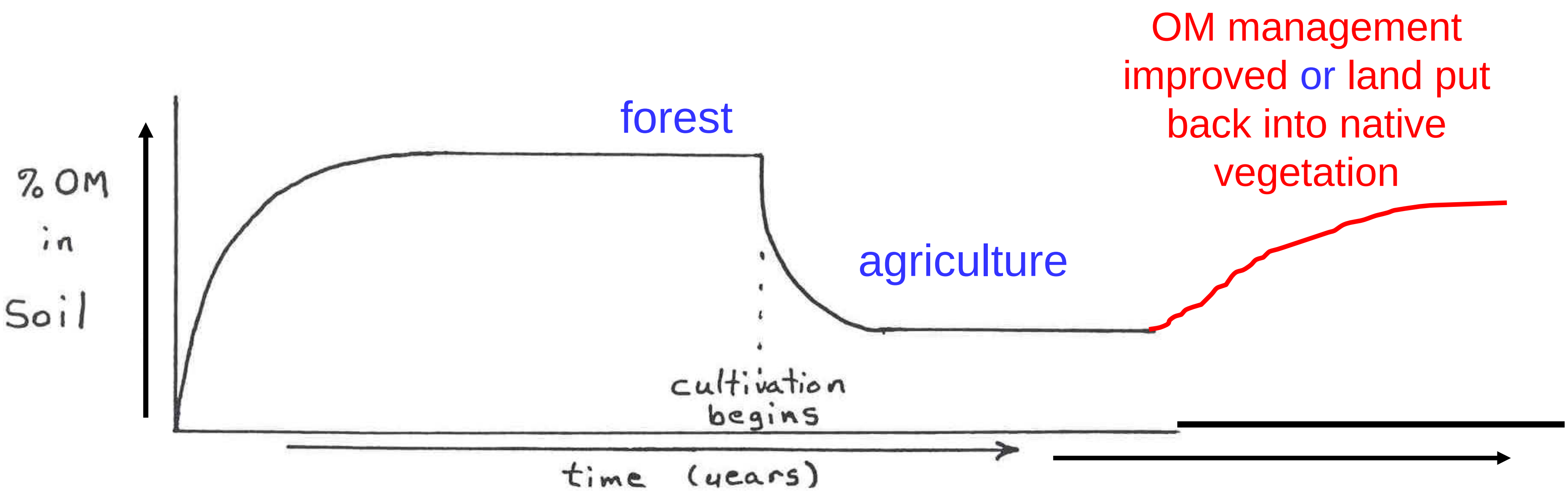
1. To dispose of organic material (e.g. sewage waste, crop residue)

2. To build up or maintain humus for
   - structure
   - water retention
   - N & S supply
   - cation retention
   - pH buffering

3. Improve water infiltration & aeration (structure-related)

4. Provide a mulch to prevent soil
   - crusting
   - erosion
   - overheating

Soil Organic Matter Management



Ways to Increase Organic Matter Levels:

1. **Reduce Losses -**
   - control erosion
   - select slowly-decaying organics
   - modify soil enviornment (aeration, etc.)
2. **Increase Inputs -**
   - add organic wastes-manures, composts
   - incorporate crop residues-green manures, straw, etc.
   - increase crop yield (fertilizer, etc.)

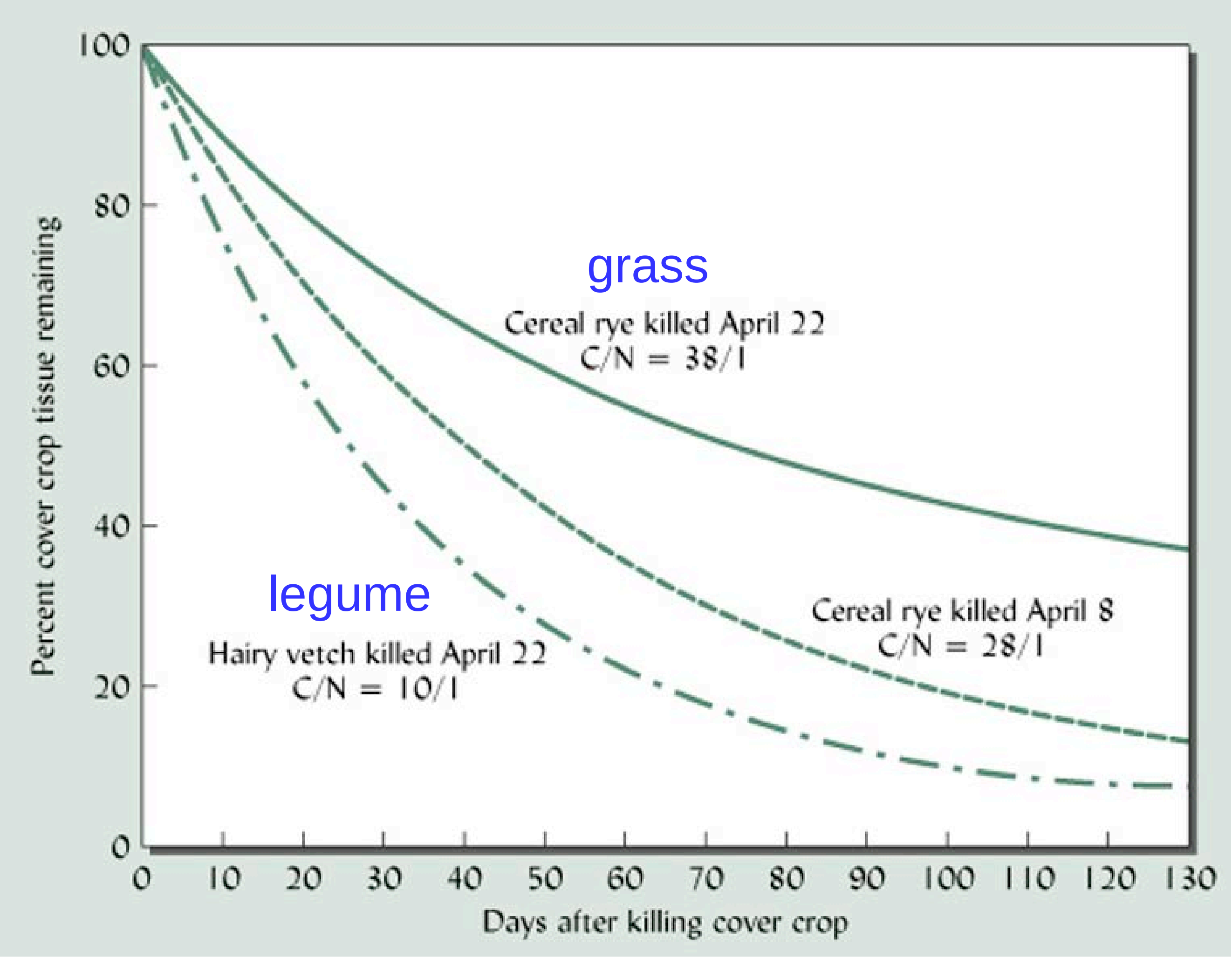
Factors controlling the rate of (S)OM Accumulation

TABLE 12.5 Factors Affecting the Balance between Gains and Losses of Organic Matter in Soils

Factors promoting gains	*Factors promoting losses*
Green manures or cover crops	Erosion
Conservation tillage	Intensive tillage
Return of plant residues	Whole plant removal
Low temperatures and shading	High temperatures and exposure to sun
Controlled grazing	Overgrazing
High soil moisture	Low soil moisture
Surface mulches	Fire
Application of compost and manures	Application of only inorganic materials
Appropriate nitrogen levels	Excessive mineral nitrogen
High plant productivity	Low plant productivity
High plant root:shoot ratio	Low plant root:shoot ratio

Factors controlling the rate of (S)OM Accumulation/Decay

C:N Ratio (in cover crops)



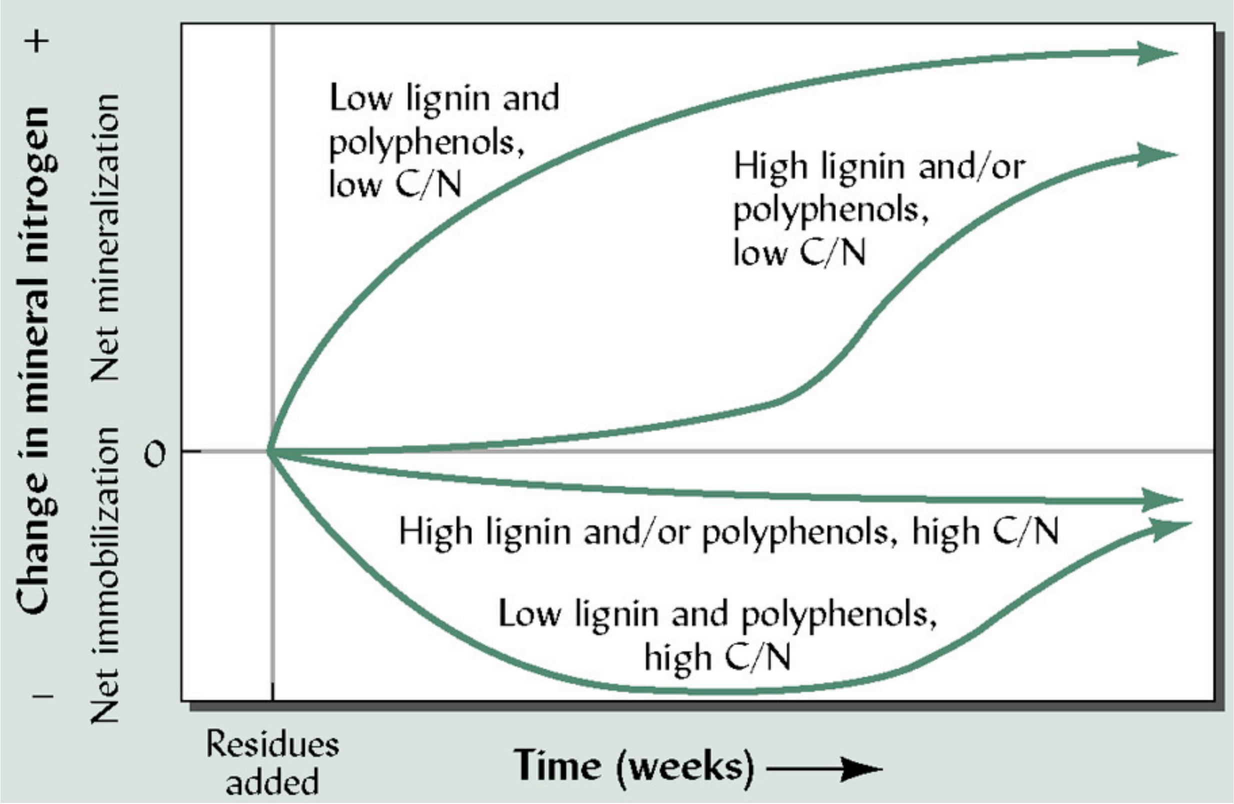
Factors controlling the rate of (S)OM Accumulation/Decay

Litter Quality:

(litter of poor quality: high C:N ratio (>30) and high contents of lignin (>20%) and polyphenols (>3%); litter with limited potential for microbial decomposition and mineralization of plant nutrients

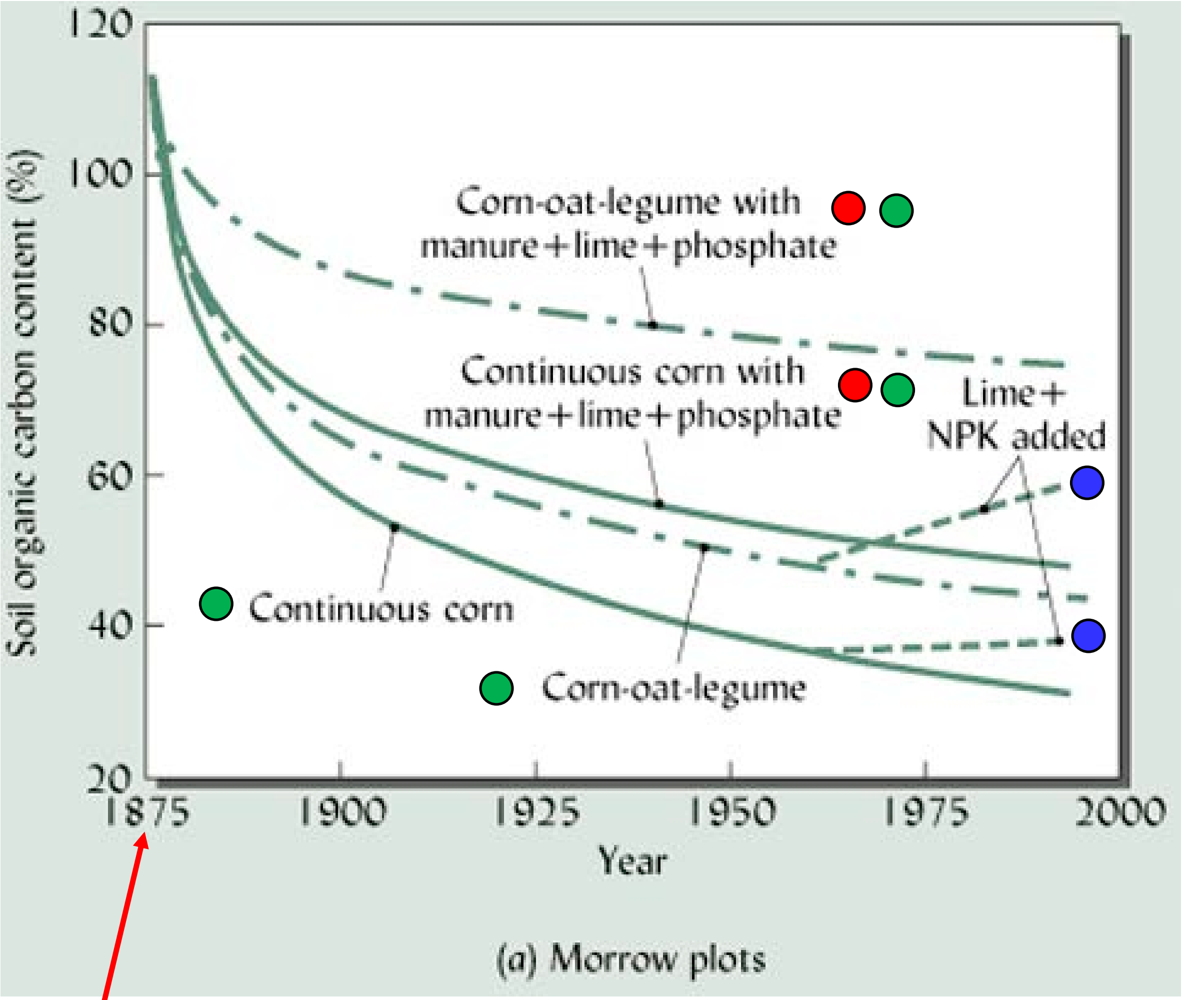
C/N < 20 (% N > 2.5) → N release

C/N > 20 (% N < 2.5) → N immobilized



Factors controlling the rate of (S)OM Accumulation/Decay

Influence of rotations, residues, and plant nutrients



virgin grassland soil

- Rotation vs continuous corn: higher SOM due to less tillage and more root residues
- Manure, lime and nutrients: higher SOM due to more OM added as manure and in residues from higher yields
- lime and nutrients: higher SOM due to more OM added in residues from higher yields and N for OM formation