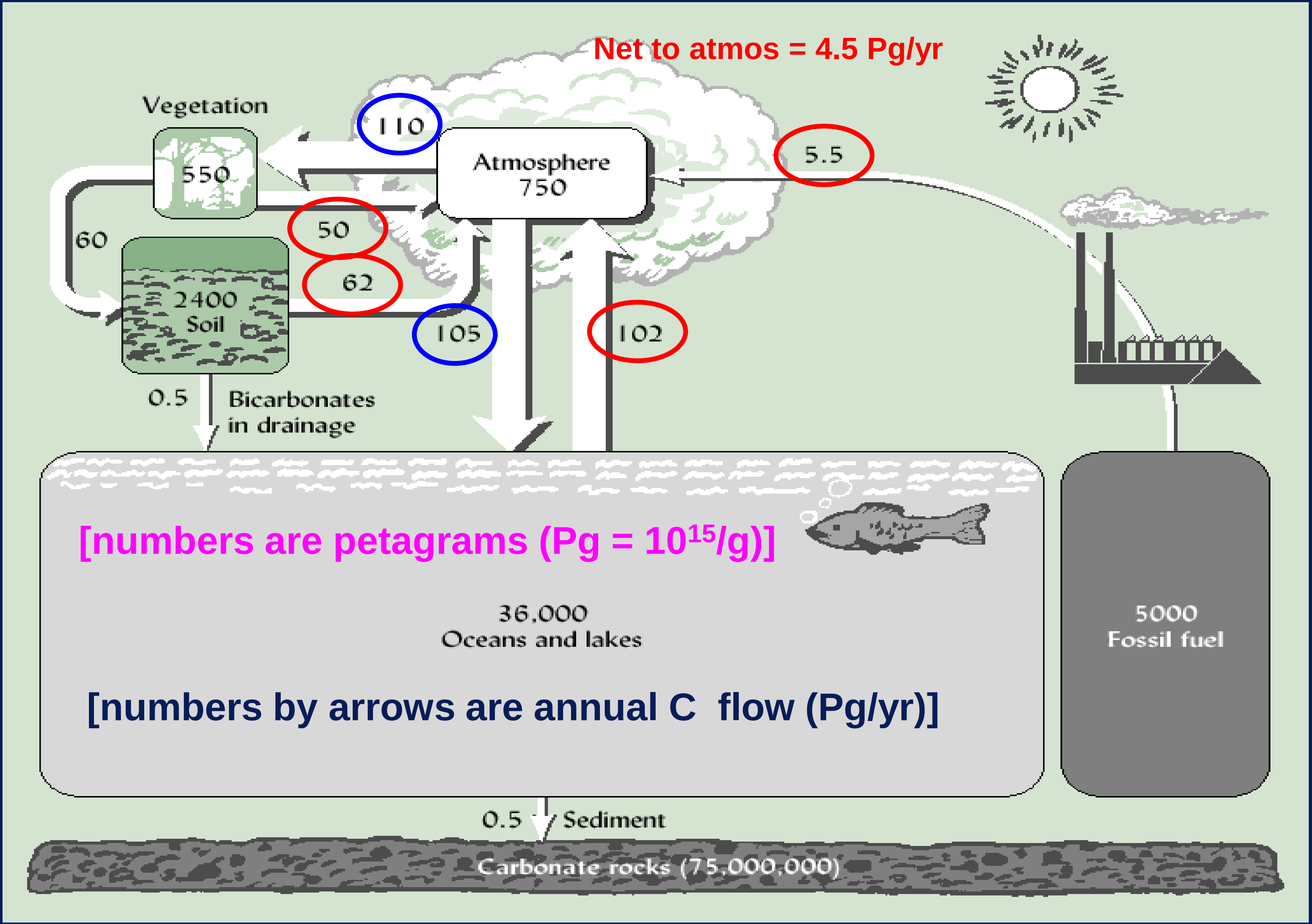
GEOL 408/508

SOIL ORGANIC MATTER

Chapter 12

Brady and Weil, Rev. 14th Ed.

GLOBAL CARBON CYCLE



THE GLOBAL CARBON CYCLE

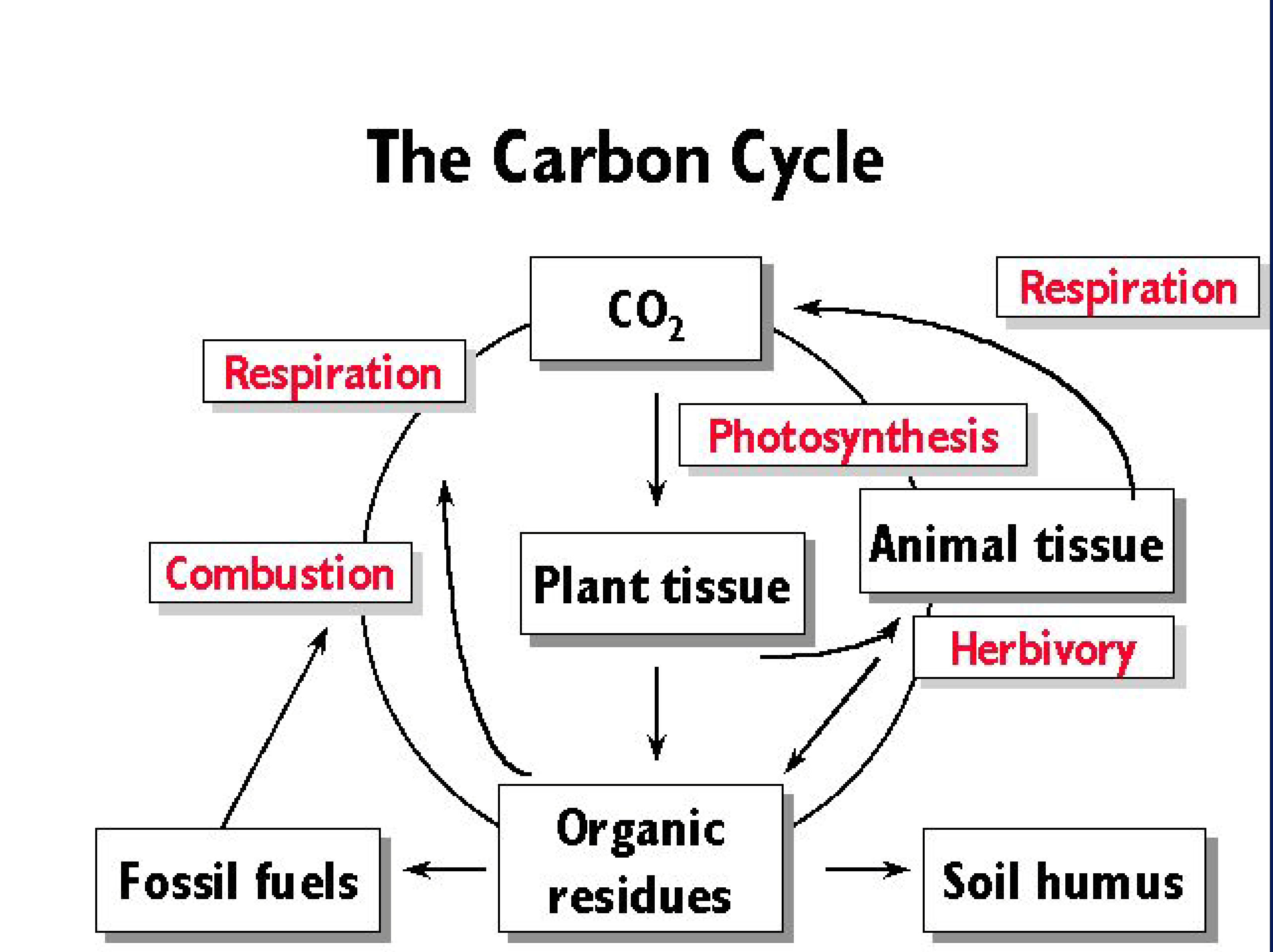
Pathways:

- Shown in Figure 12.3
- Soil is a significant reservoir of C
- Net accumulation of CO_2 in the atmosphere

Carbon sources:

- Original source of soil OM is plant tissue; animals are secondary sources
- About 2X as much C is stored in the soil than in world's vegetation plus the atmosphere
- About 45% C is found in Histosols, Inceptisols & Gelisols
- In mature ecosystem, Soil C_{in} = Soil C_{out}

THE CARBON CYCLE - 2



THE PROCESS OF DECOMPOSITION IN SOILS

Composition of plant residues:

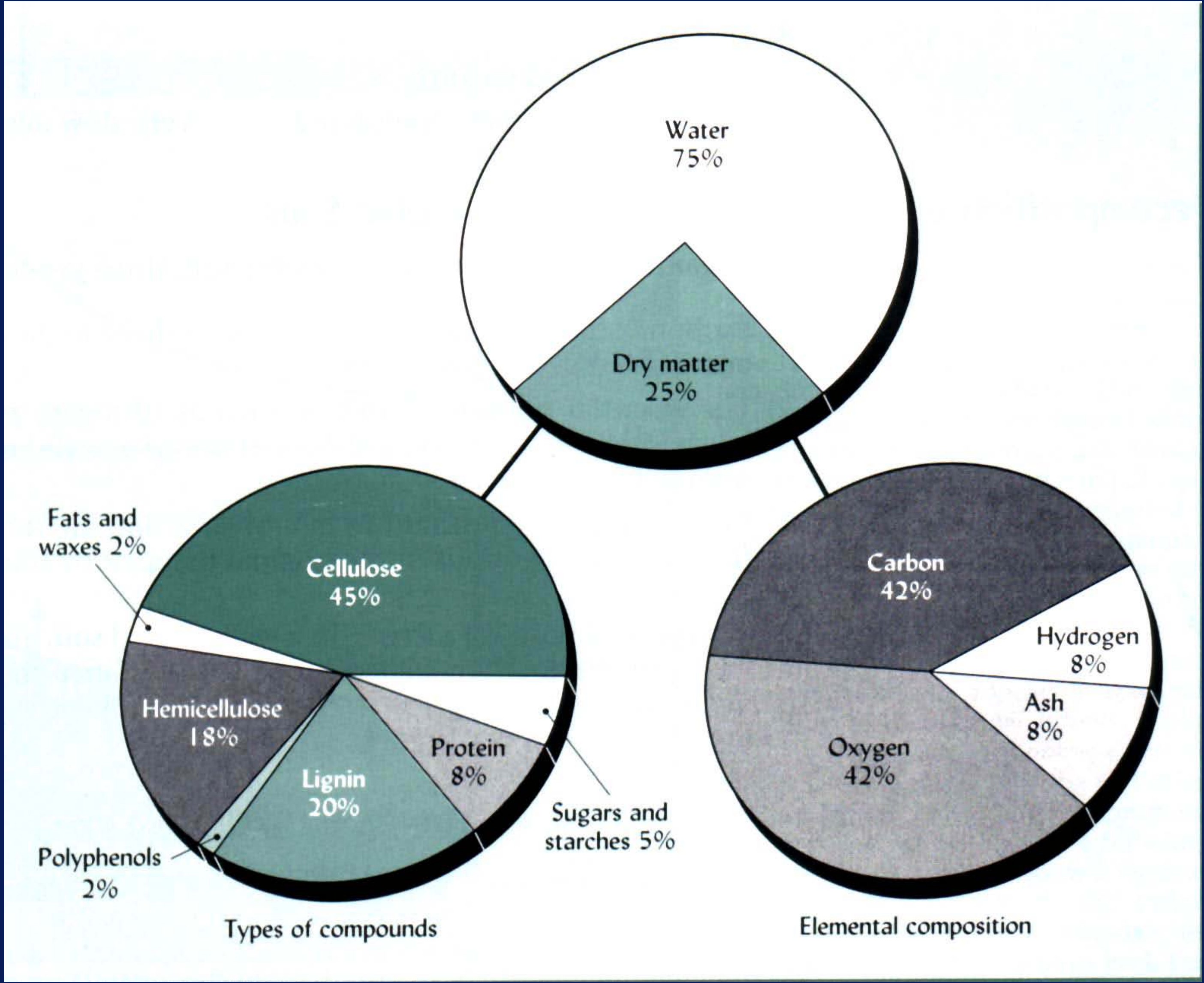


Fig 12.4

THE PROCESS OF DECOMPOSITION IN SOILS - 2

Composition of plant residues:

Rates of decomposition:

1. Sugars, starches, simple proteins
2. Crude proteins
3. Hemicellulose
4. Fats, waxes, etc.
5. Lignins & phenolic compounds

Rapid decomp

↓

Very slow decomp

THE PROCESS OF DECOMPOSITION IN SOILS - 3

Decomposition of organic compounds in aerobic soils:

When organic tissue is added to an aerobic soil:

1. C compounds are enzymatically oxidized to CO_2, H_2O, E & decomposer biomass
2. Nutrient elements, N, P, S, etc., are released and/or immobilized by element specific reactions
3. Compounds very resistant to microbial action are formed by degradation and/or synthesis reactions

- **Decomposition: An oxidative process:**

$$R\text{-}(C, 4H) + 2O_2 \xrightarrow[\text{oxidation}]{\text{Enzymatic}} CO_2\uparrow + 2H_2O + E \ (478 \text{ kJ mol}^{-1} \text{ C})$$

THE PROCESS OF DECOMPOSITION IN SOILS - 4

Decomposition of organic compounds in aerobic soils:

- **Breakdown of proteins:**
  - plant proteins are broken down, but others may be synthesized, e.g., glycine (CH_2NH_2COOH)
  - these newly synthesized proteins are ultimately broken down & release contained nutrients

- **Breakdown of lignin:**
  - very resistant to decomposition
  - few organisms (a few fungi) are able to break down lignin
  - after partial decomposition, other microbes are able to attack subunits

THE PROCESS OF DECOMPOSITION IN SOILS - 5

Example of organic decay:

(Time sequence is illustrated in Fig. 12.3)

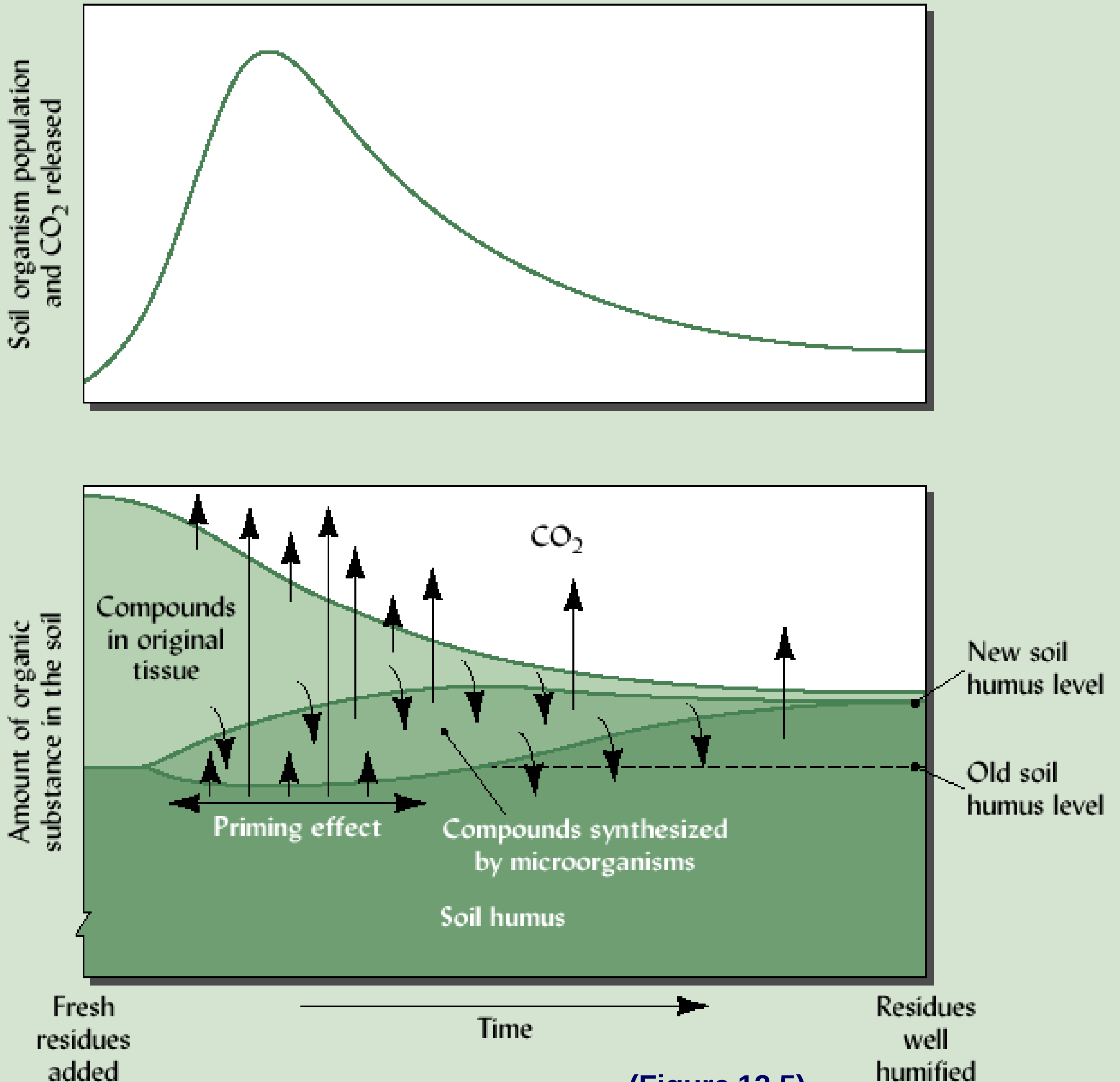
Starting with soil having no readily decomposable materials:

- active microbes are autochthonous organisms, which digest very resistant, soil OM
- food supply is limited, total respiration is low

Fresh, decomposable tissue is added:

- zygmogenous (opportunist) organisms rapidly become dominant groups of organisms
- easily decomposed materials are first exhausted
- more resistant materials are decomposed, at slower rates
- there will be a net increase in soil humus

Changes that take place when fresh residues are added to the soil.



(Figure 12.5)

THE PROCESS OF DECOMPOSITION IN SOILS - 6

Decomposition in anaerobic soils:

- decomposition proceeds very slowly in absence of O_2
- decomposition products are composed of partially decomposed products
- typical gaseous products are CH_4, H_2S, CO_2,

Production of simple inorganic products:

- mineralization is the process of liberating elements from organic compounds to inorganic forms
- most important are: NH_4^+, S^{-2}; then NO_3^-, SO_4^{-2}

FACTORS CONTROLLING RATES OF DECOMPOSITION & MINERALIZATION

Physical factors influencing residue quality:

Residues on surface are decomposed more slowly than those incorporated into soil

Smaller sized materials are decomposed more rapidly
- **greater surface area**
- **breakage may expose more susceptible parts of waxy coated materials**

Carbon/nitrogen ratio of OM and soils:

Typical plant dry matter: C = 40-58%; N = <1->6%
C/N ratio is important because:
- **intense competition for N with high C/N OM**
- **C/N helps determine rate of decay & N availability**

FACTORS CONTROLLING RATES OF DECOMPOSITION & MINERALIZATION

Carbon/nitrogen ratio of OM and soils:

- **C/N ratio in plants & microbes:**
  - in plants, ratio ranges from 10:1-30:1 to 600:1
  - C/N increases as plants mature
  - in microorganisms, ratio is 5:1 to 10:1

- **C/N ratio in soils:**
  - in cultivated surface horizons, 8:1 to 15:1
  - ratio is generally lower for subsoils
  - Mollisols & tropical Alfisols, ratio is narrow
  - leached & acidic A horizonsin humid regions, ratio is wide, up to 30:1

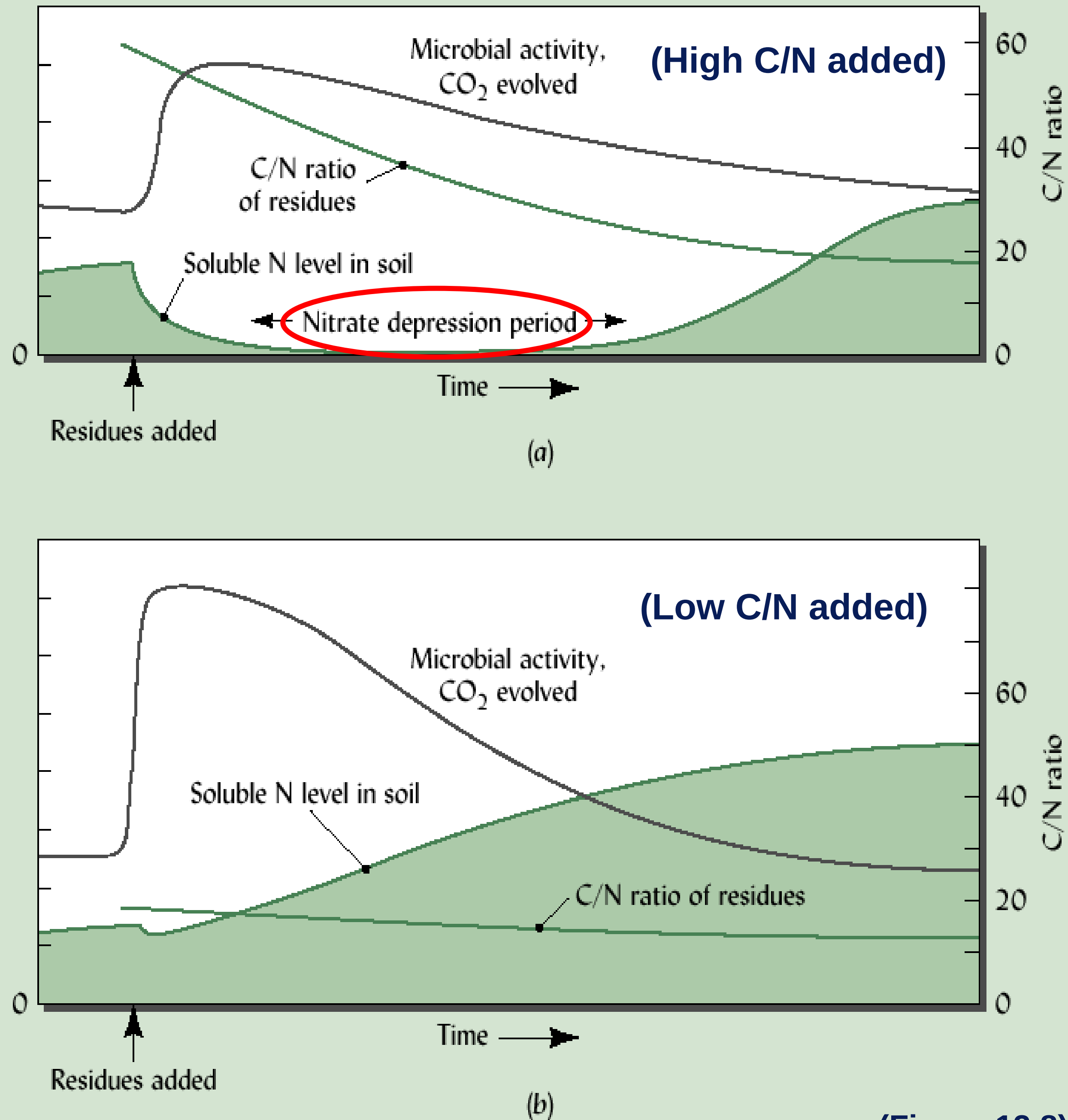
FACTORS CONTROLLING RATES OF DECOMPOSITION & MINERALIZATION

Influence of C/N ratio on decomposition:

- soil microbes need both C and N for growth
- these organisms need to incorporate eight parts C for each part N
- about one-third C metabolized is incorporated into cells
- microbes need 1g of N for each 24g C
- if plant residues have C/N > 25:1, microbes will have to obtain N from soil solution
- this action may deplete soil N such that N-deficiency occurs in higher plants
- if sufficient N is not available, decay of OM may be delayed

Examples of Inorganic N Release During Decay

Changes following addition of OM having a (a) wide and (b) narrow C/N ratio to soils



(Figure 12.8)

FACTORS CONTROLLING RATES OF DECOMPOSITION & MINERALIZATION

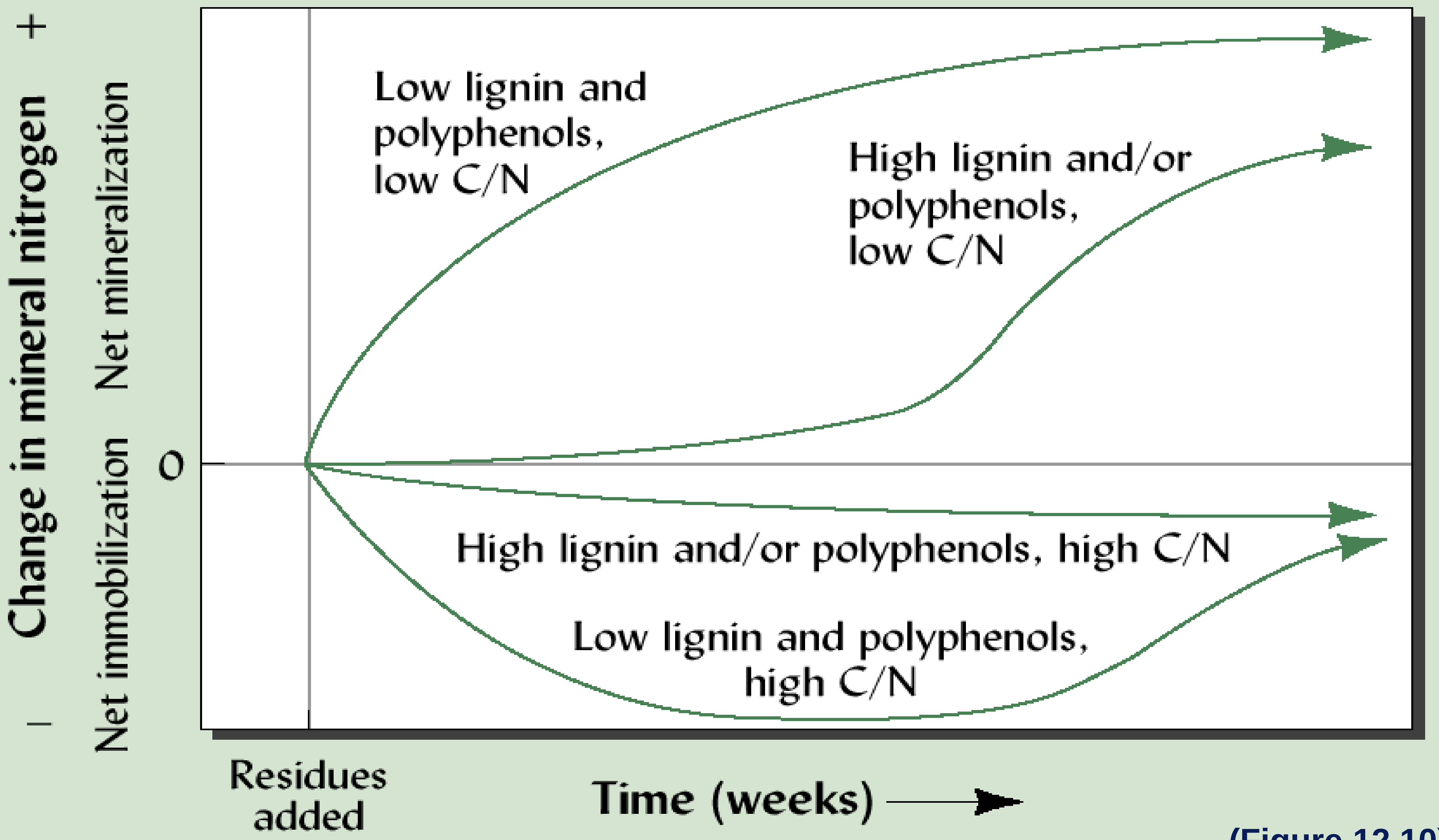
Influence of soil ecology:

- nutrients released by OM decay move through and up the food web
- many organisms that feed on microbes will release more N than they use, mostly as NH_4^+, which is plant available
- a complex food web generally enhances cycling & efficient use of N

Influence of lignin & polyphenol content of OM:

- residues high in these two constituents will decompose very slowly (Fig. 12.8)
- such materials are considered poor quality resources

TEMPORAL PATTERNS OF NITROGEN RELEASE



(Figure 12.10)

HUMUS: GENESIS AND NATURE

Microbial transformations:

Decomposition and synthesis reactions form ill-defined, complex, resistant, polymeric compounds called humic substances

Humic substances:

- **fulvic acid, humic acid & humin (Fig. 12.11)**

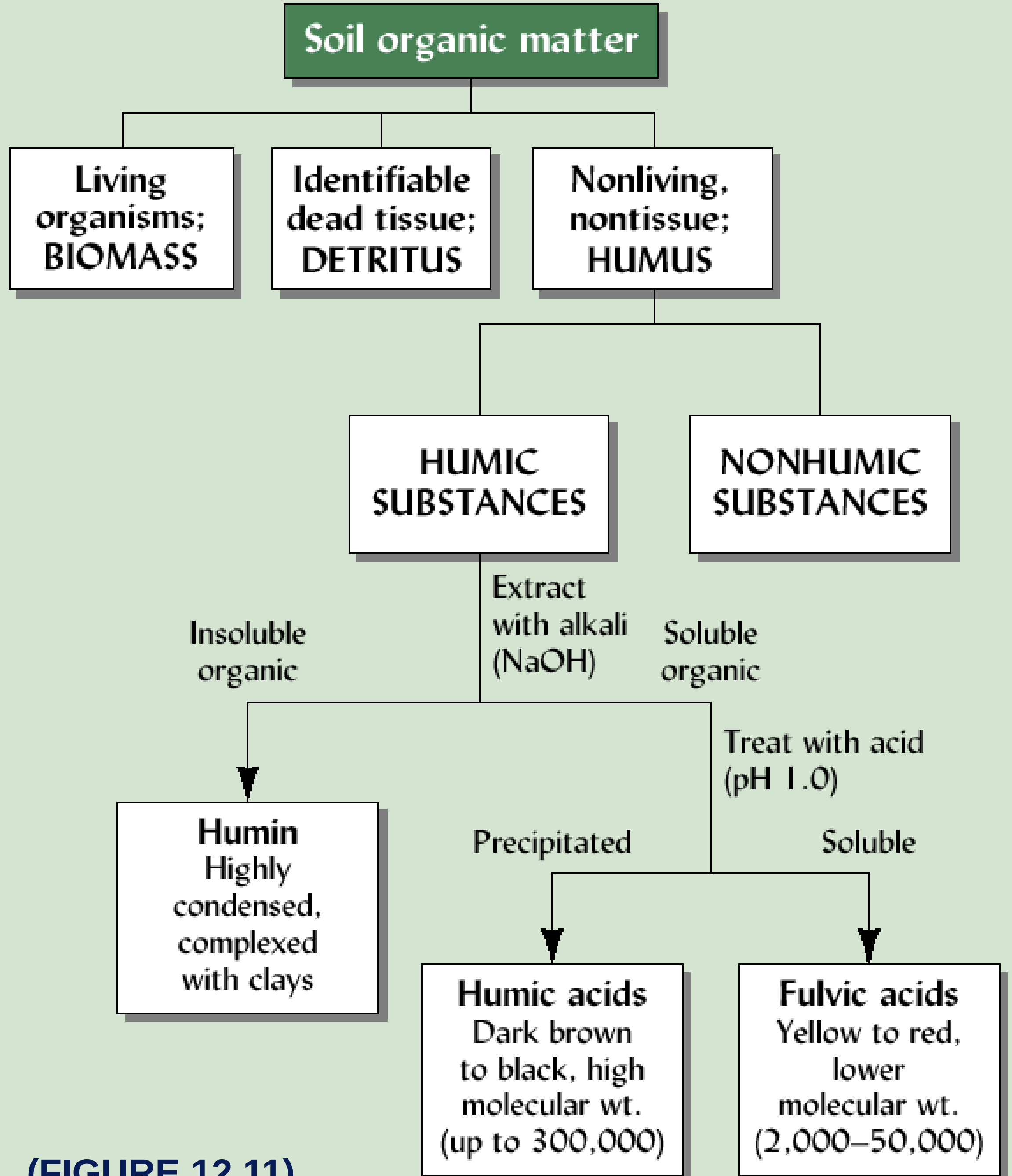
Nonhumic substances:

- **polysaccharides & polyuronides**

Stability of humus:

- **stable over hundreds to thousands of years**
- **clay-humus complexes provide long-term protection of organic molecules, even proteins**

CLASSIFICATION OF SOIL ORGANIC MATTER



(FIGURE 12.11)

COMPOSTS AND COMPOSTING

Compost is aerobically decomposed OM that is produced outside of the soil

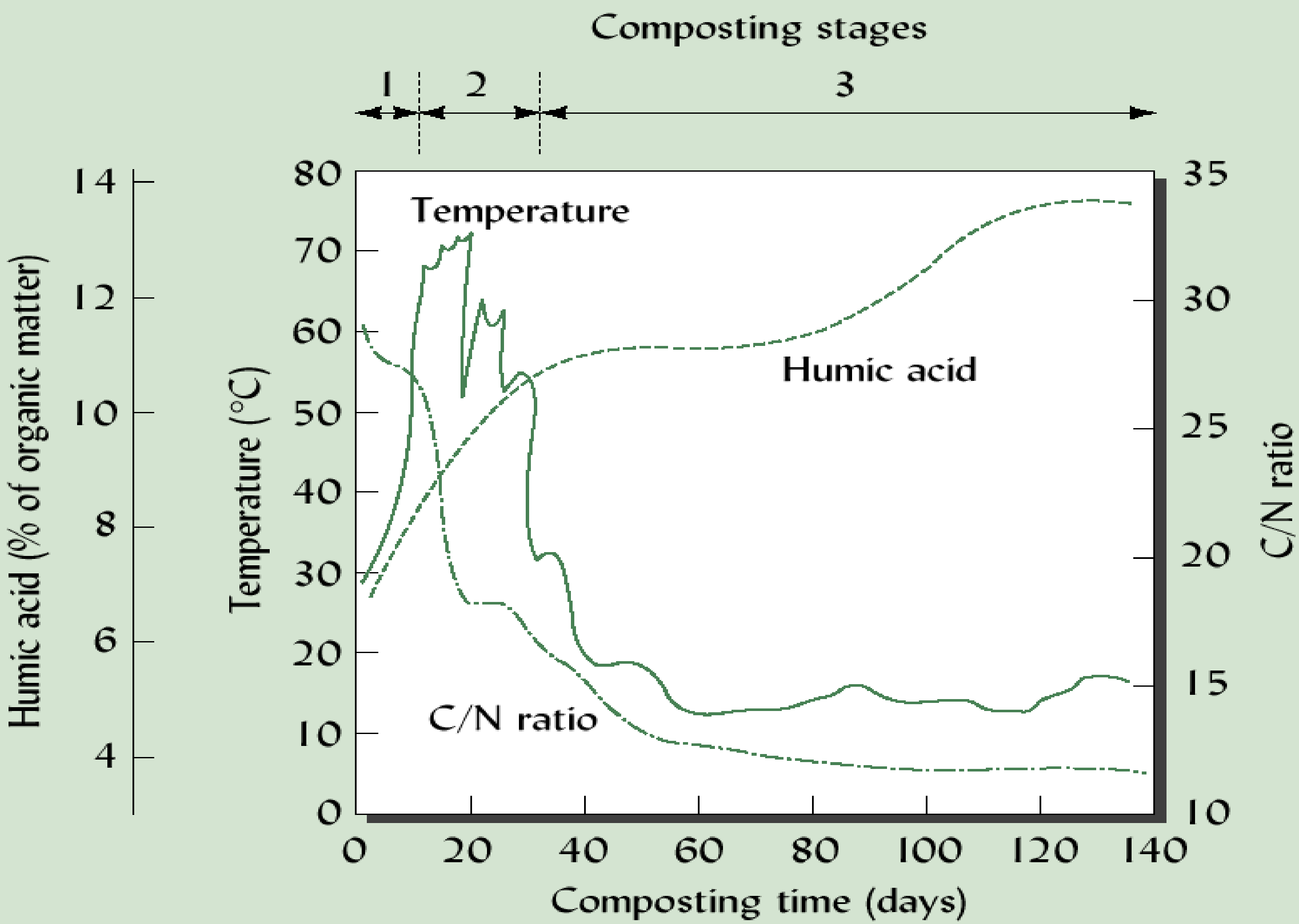
Composting process (Fig, 12.33):

(1) mesophilic stage where simple food sources are utilized & temps rise to >40ºC

(2) thermophilic stage where temps rise to 50-75 ºC and more resistant compounds are decomposed - must mix often

(3) curing stage where mesophilic organisms that produce plant-growth-stimulating compounds or are antagonistic to plant pathogenic fungi

CHANGES DURING COMPOST PRODUCTION



(Figure 12.33)

COMPOSTS AND COMPOSTING

Nature of the compost produced:

- C/N decreases to 14:1 to 20:1
- CEC increases to about 50-70 $cmol_c/kg$
- nutrients are concentrated
- weed seeds & pathogenic organisms are generally destroyed

Benefits of composting:

- safe storage
- easier handling
- N competition avoidance
- N stabilization
- partial sterilization
- detoxification
- disease suppression

DIRECT INFLUENCES OF OM ON PLANT GROWTH

Direct effect of humus on plant growth:

- humus contains various growth-promoting compounds such as auxins & gibberellins
- enhancing effect of fulvic & humic acids

Allelochemical effects:

- allelopathy is process where one plant infuses the soil with a chemical that affects growth of other plants
- produced by (1) direct exudation, (2) leaching from foliage or (3) microbial metabolosm of dead plant tissue
- are mostly negative effects, generally species specific

INFLUENCE OF OM ON SOIL PROPERTIES AND THE ENVIRONMENT

Influence on soil physical properties:

- dark brown to black color
- influence on granulation & aggregate stability
- reduce plasticity, cohesion, stickiness

Influence on soil chemical properties:

- humus gen accounts for 50-90% CEC of min soils
- buffering action
- humic acids accelerate decomp of minerals

Biological effects:

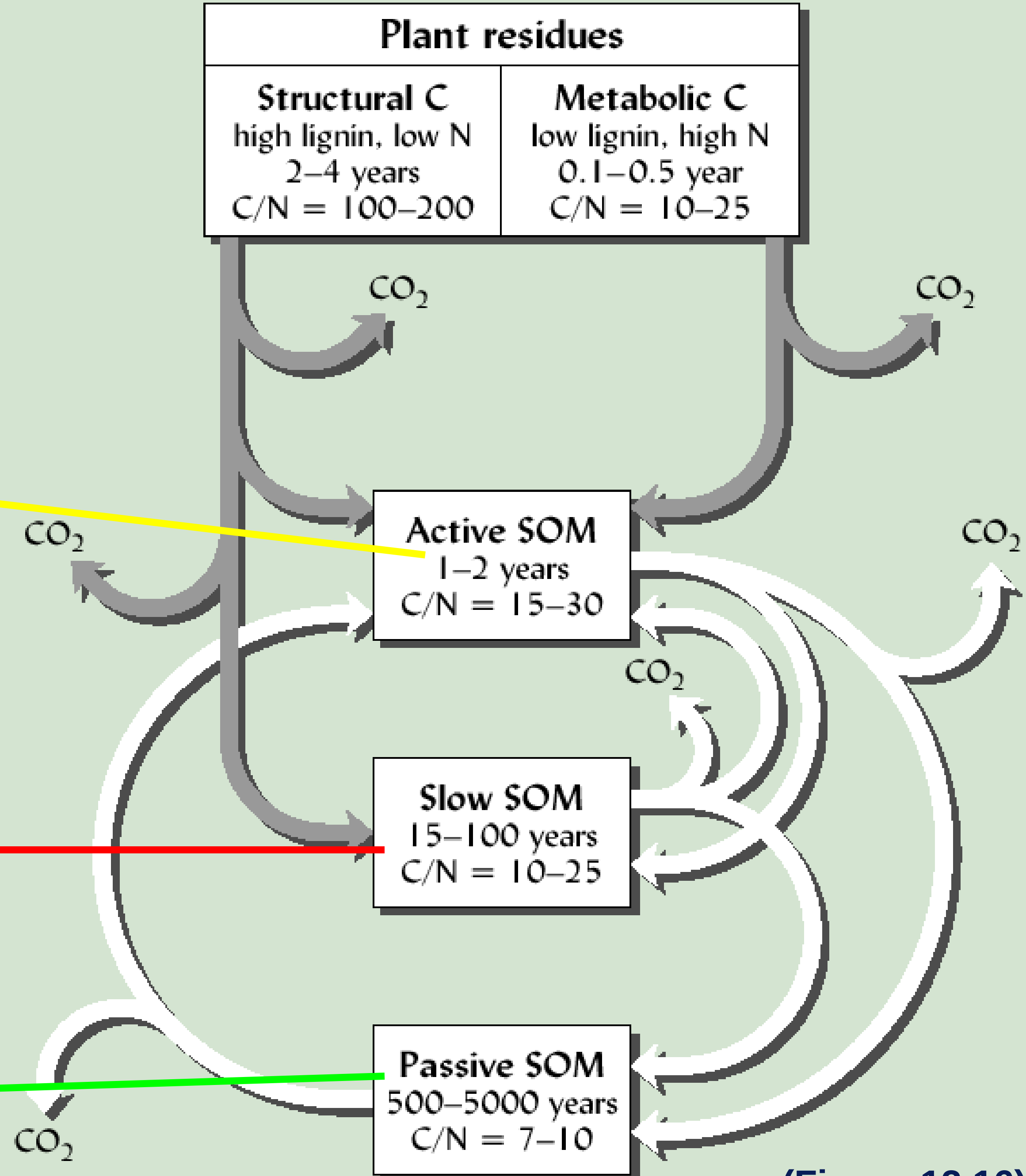
- nature & quality of OM affects type & diversity of soil organisms present
- nature & quality of OM affects rates of decomp.

CONCEPTUAL MODEL OF SOIL ORGANIC MATTER

Living biomass, some fine particles of detritus, polysaccharides & other nonhumics

Finely divided plant tissues high in lignin & other slowly decomposable & chem resistant components

Humus, clay-humus complexes, humin; 60-90% of soil OM



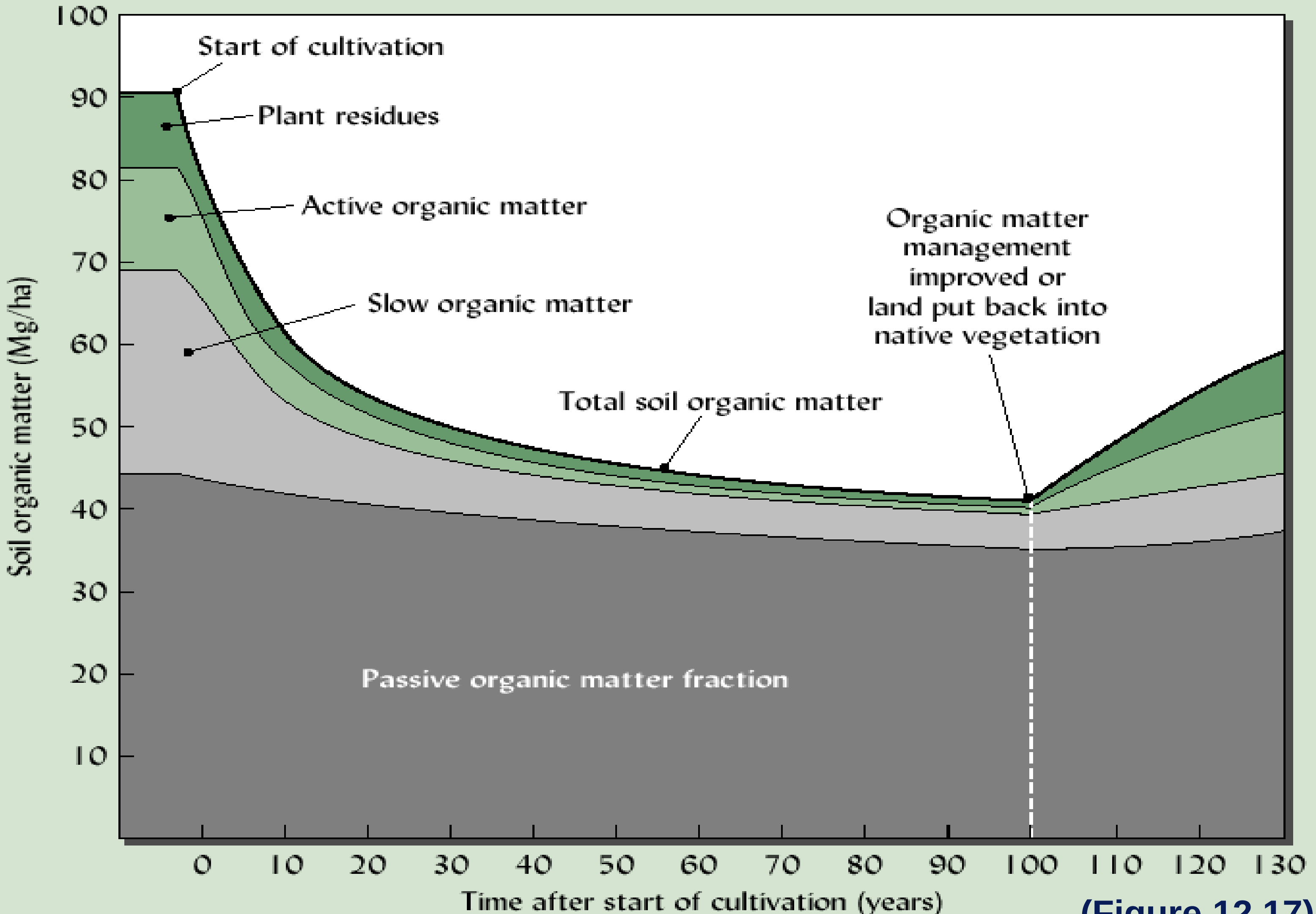
(Figure 12.16)

MANAGEMENT OF AMOUNT AND QUALITY OF SOIL OM

Changes in active and passive fractions with soil management:

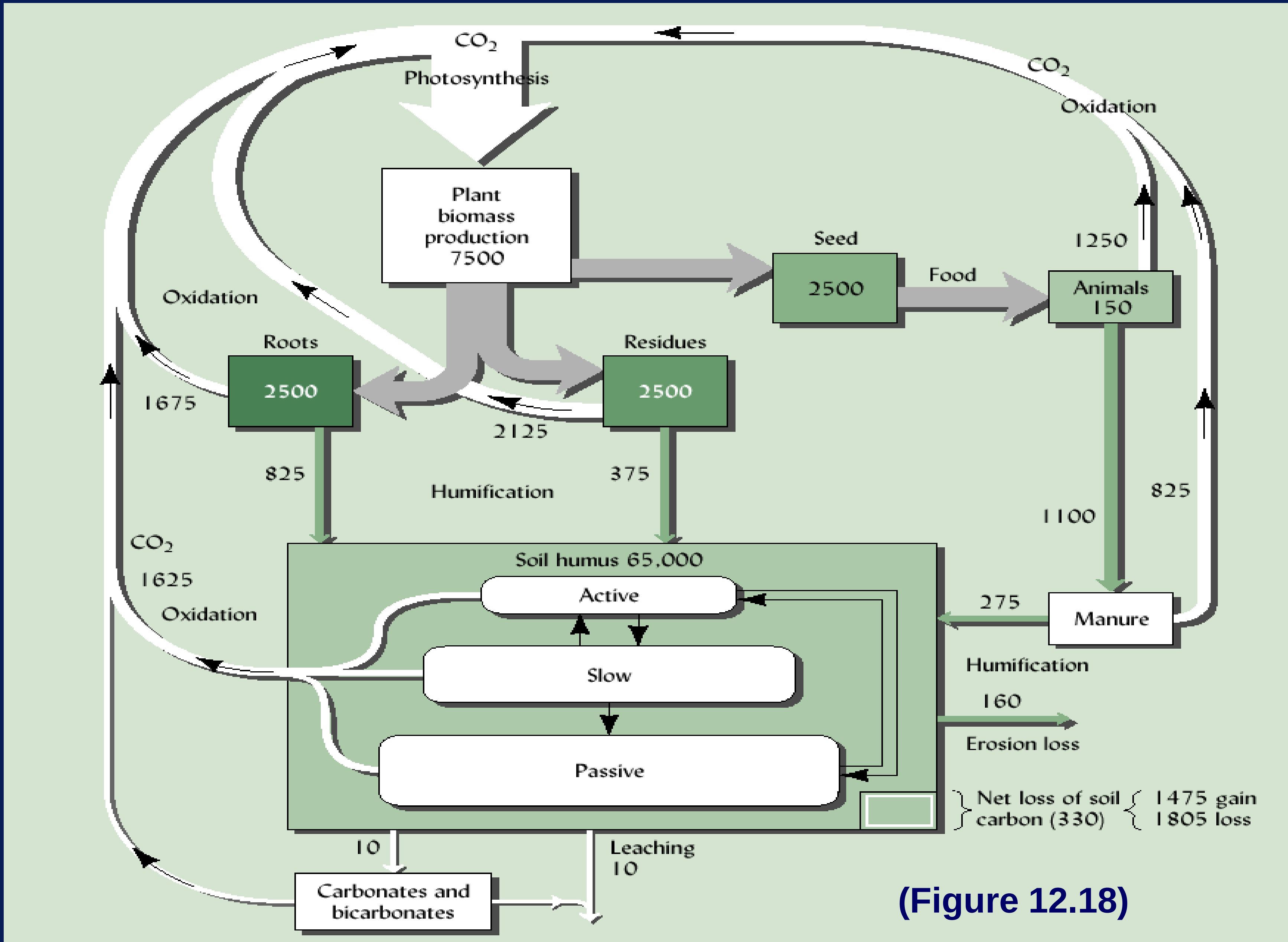
- **Active and slow fractions respond most quickly to changes in soil management practices**
- **More productive soils are associated with higher proportions of the active fraction of OM**
- **Active pool very important in aggregate stability & N mineralization rate**
- **Management practices that cause small changes in total OM may cause pronounced changes in aggregate stability & N mineralization rate due to the effect on the active fraction**

CHANGES IN SOIL OM AFTER INITIATION OF CULTIVATION



(Figure 12.17)

CARBON CYCLING IN AN AGROECOSYSTEM



(Figure 12.18)

CARBON BALANCE IN THE SOIL-PLANT-ATMOSPHERE SYSTEM

Agroecosystems:

Conservation of soil carbon: (Refer to Fig 12.18)

- In order to halt net C loss, need practices that (1) increase additions or (2) decrease losses
- use better erosion control; use conserv’n tillage
- add more OM to system

Natural ecosystems:

Forests:

- humus oxidation would be less than in tilled field
- surface deposition; more resistant material

Grasslands:

- similar trends to forests
- more OM from roots; more at greater depth

FACTORS AND PRACTICES INFLUENCING SOIL OM LEVELS

Differences among soil orders:

- Aridisols generally have lowest OM content
- Histosols obviously have highest OM content
- Forested soils in humid tropics (Oxisols, some Ultisols) contain levels similar to those in humid temperate regions (Alfisols, Spodosols)
- Andisols generally have some of highest OM levels
- General decrease in OM with depth; differences in distribution patterns

VERTICAL DISTRIBUTION OF ORGANIC CARBON IN WELL-DRAINED SOILS OF FOUR SOIL ORDERS.

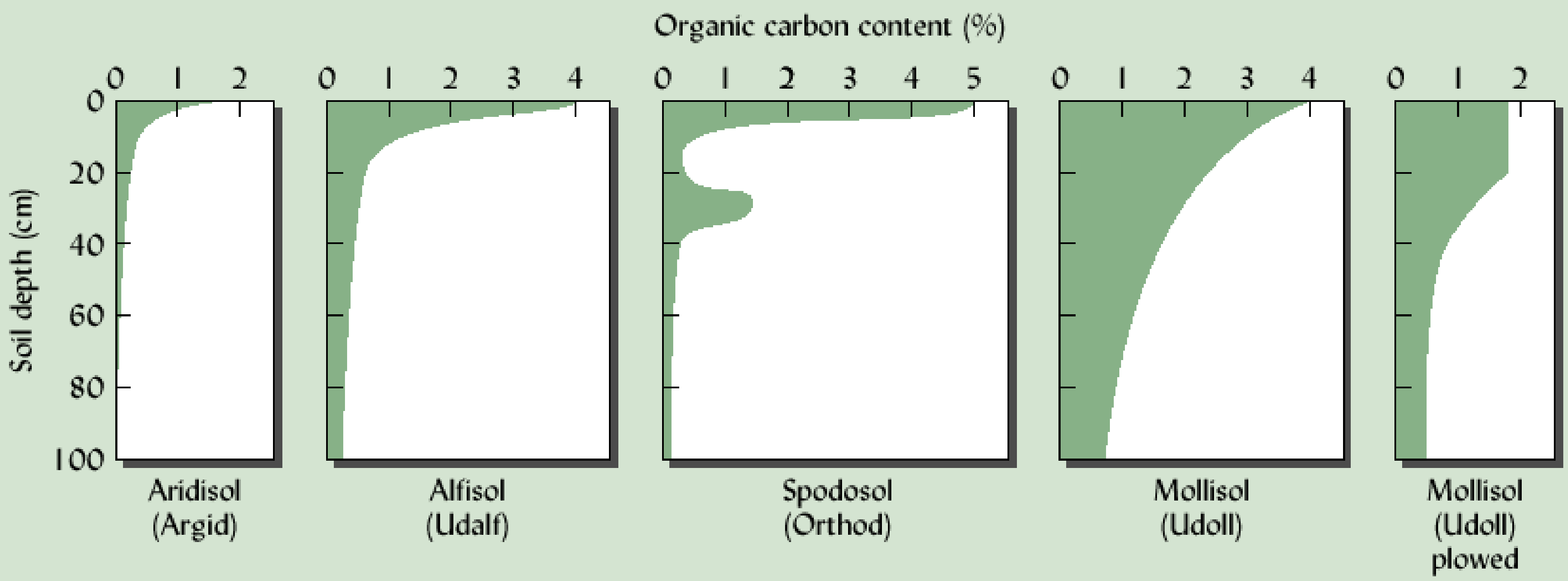


Fig. 12.19

FACTORS AND PRACTICES INFLUENCING SOIL OM LEVELS

Influence of climate:

Temperature: (Fig. 12.20)

- organic matter **production** increases with temp
- organic matter **destruction** increases with temp
- Net OM = (production) - (destruction)
- destruction > production at T >25ºC
- OM & N increase 2-3X for each 10ºC T decrease

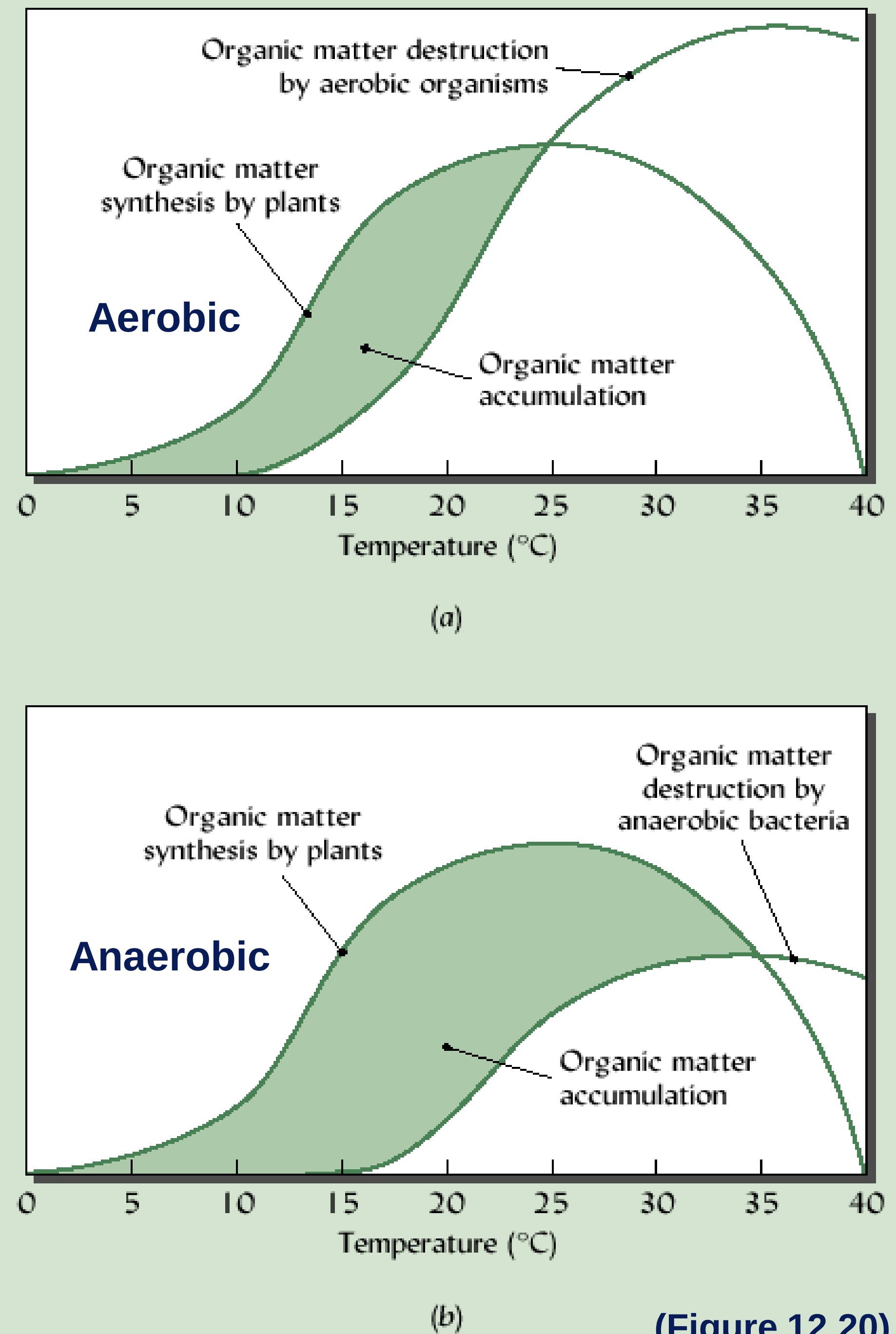
Moisture:

- OM & N increase as effective moisture increases
- C/N ratio tends to be greater in high rainfall areas

OM is influenced by temp, moisture, tillage, vegetation, slope, aspect & soil texture

FACTORS AND PRACTICES INFLUENCING SOIL OM LEVELS-2

Balance between plant production & biological oxidation of OM - Net OM accumulation in soils under aerobic & anaerobic conditions



(Figure 12.20)

FACTORS AND PRACTICES INFLUENCING SOIL OM LEVELS - 3

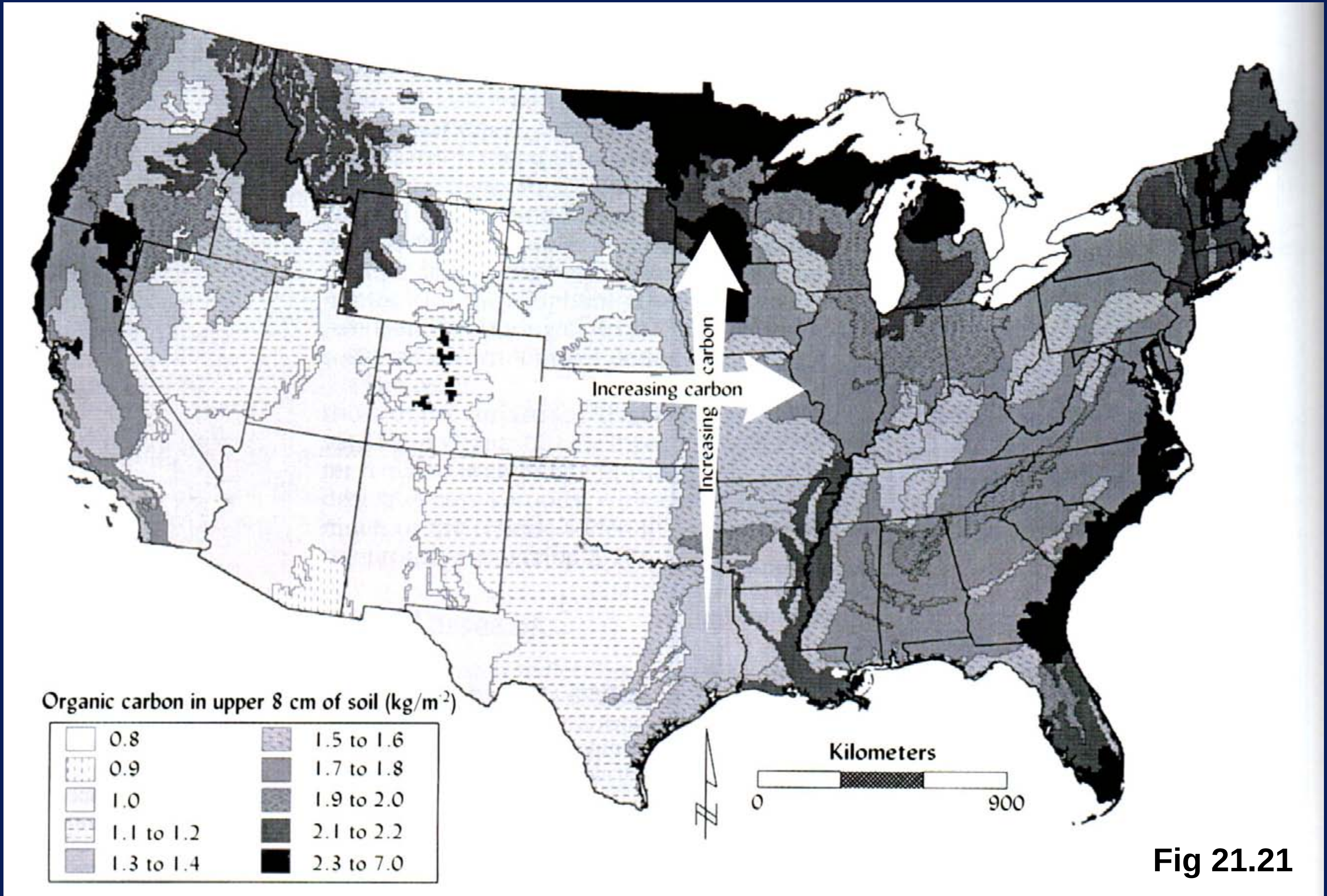


Fig 21.21

FACTORS AND PRACTICES INFLUENCING SOIL OM LEVELS - 4

Influence of natural vegetation:

- previously discussed: grassland vs forest
- where grassland & forest both occur in same climatic zone, more OM in grassland soils

Effects of texture and drainage:

Texture effects:

- greater OM in finer textured soils
- max amount of humus present related to %clay

Drainage effects:

- poor drainage promotes plant production
- poor aeration inhibits OM destruction

FACTORS AND PRACTICES INFLUENCING SOIL OM LEVELS - 5

Influence of agricultural management and tillage:

- cultivated land contains lower levels of OM & N than comparable areas under natural vegetation

Conversion to cropland:

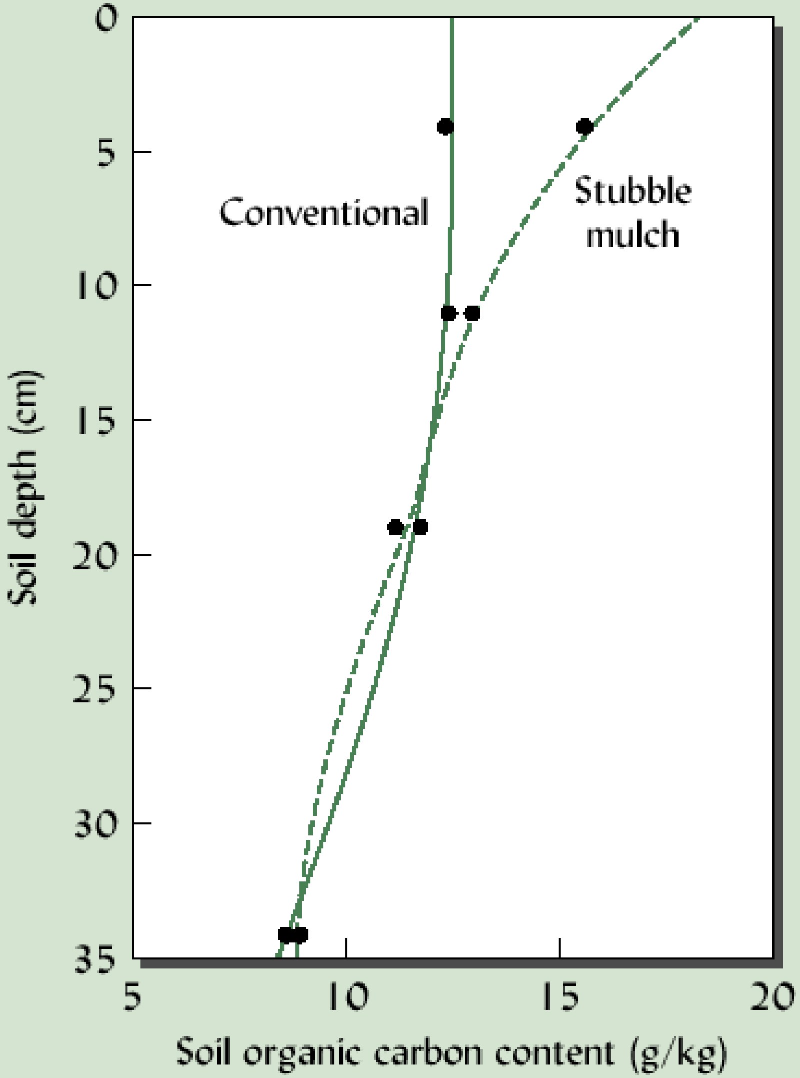
- rapid decline in OM content after initiation of cult'vn
- ultimately OM reaches new (lower) equilibrium level
- new OM levels depend upon crops grown

Influence of rotations, residues & plant nutrients:

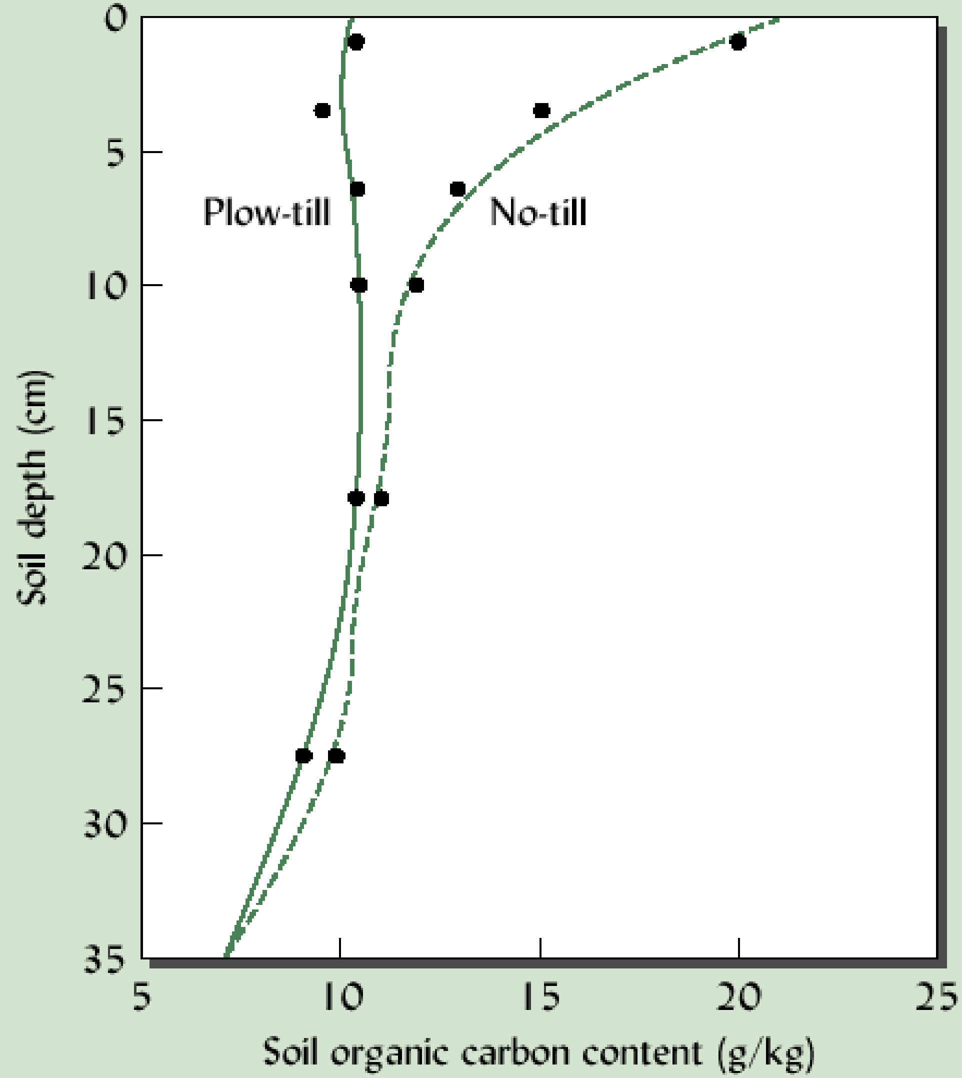
Note the conclusions drawn from:

- the Morrow plots (since 1875 at U. of IL)
- Rothamstead exprs (since 1850 in England)
- maintenence of high productivity with add'ns of lime, nutrients and OM will give soils with higher levels of OM than low productivity soils

EFFECTS OF TWO CONSERVATION TILLAGE SYSTEMS ON SOIL ORGANIC CARBON CONTENT



(*a*) Stubble mulch tillage in Oregon



(*b*) No-till in Maryland

FACTORS AND PRACTICES INFLUENCING SOIL OM LEVELS - 6

Recommendations for managing soil OM:

1. Must continuously add supply of organic materials; plant residues, manures, composts & org wastes are primary sources
2. Try to maintain the OM levels that the soil-plant-climate control mechanisms dictate - i.e., what is reasonable for the soil type (texture) where I am?
3. Ensure that sufficient levels of N are maintained
4. Maximum plant growth increases amount of OM added to soil
5. Minimize tillage to minimize OM oxidation
6. Perennial vegetation - encourage & maintain

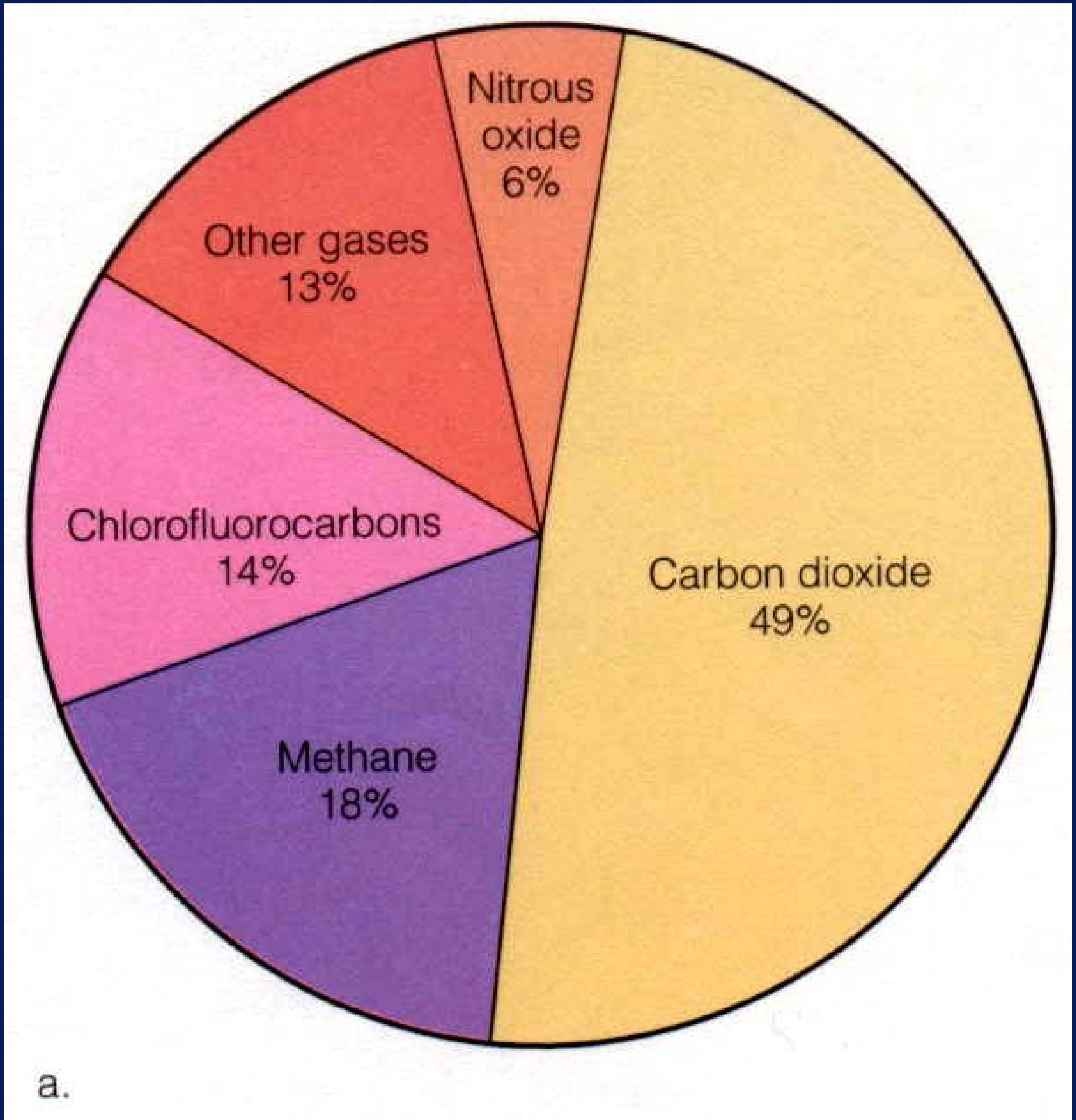
SOILS AND THE GREENHOUSE EFFECT

Soil is a major component of the Earth's system of self regulation - remember that relatively small changes may sometimes upset an equilibrium!

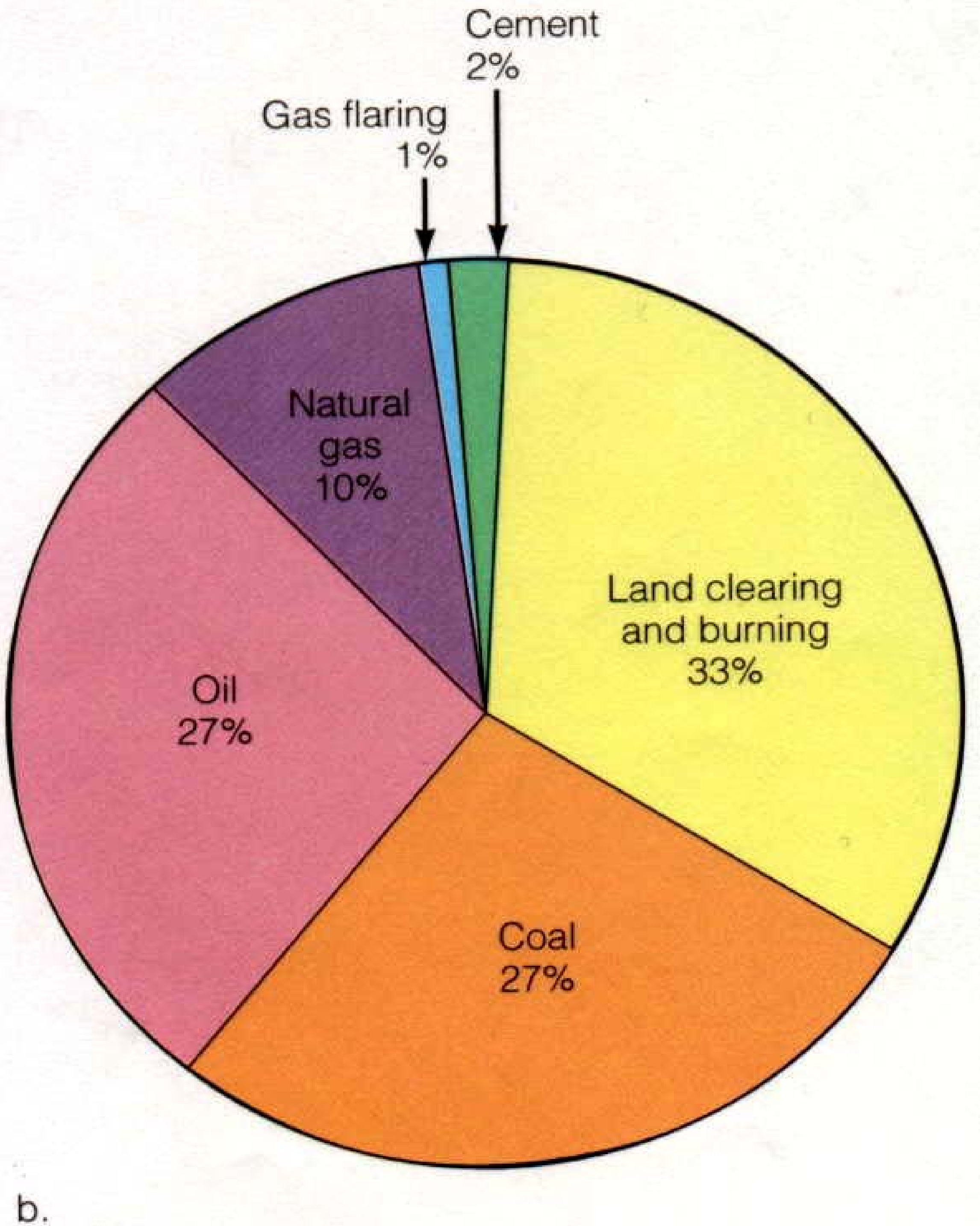
Global warming:

- Concentrations of most greenhouse gases are increasing (CO_2 increase of 0.5% per year)
- Actual rise in global temperature is less certain
- Many studies on sequestering of C in soils & plants - no universal conclusions at this time
- CH_4 is produced in weland & rice paddy soils, termite and ruminate guts & landfills

GREENHOUSE GAS CONTRIBUTIONS TO GLOBAL WARMING



SOURCES OF CO_2 FROM HUMAN ACTIVITIES



EARTH'S AVERAGE TEMPERATURE