Soil Organic Matter

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Ecological Agriculture

Cornerstone of organic agriculture

- Organic matter content of soil is the most single important

- Rodale vs. Sir Albert Howard
  - Is adding organic matter is sufficient or need to pay attention to minerals as well?

Why important?

- Soil quality (the capacity of the soil to function to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation) depends on quality and quantity of soil organic matter
- Three times more C in soil than in world's vegetation
    - Important in global warming

Outline

- The C cycle
- C in soil pools
- Management of SOC
- Questions BW CH 12

SOM can naturally vary from <1 to 47%

TABLE 12.1 Mass of Organic Carbon in the World's Soils

Values for the upper 1 m represent most of the carbon in the soil profile. The upper 15 cm generally represents the surface soil, which is most readily influenced by land use and soil management.

		Organic carbon[a] in upper 100 cm			Organic carbon[a] in upper 15 cm	
Soil order	Global area, 10^3 km^2	Mg/ha	Global Pg[b]	% of global	Range,[c] %	Typical,[c] %
Entisols	14,921	99	148	9	0.06–6.0	—[d]
Inceptisols[e]	21,580	163	352	22	0.06–6.0	—[d]
Histosols[e]	1,745	2,045	357	23	12–57	47
Andisols	2,552	306	78	5	1.2–10	6
Vertisols	3,287	58	19	1	0.5–1.8	0.9
Aridisols	31,743	35	110	7	0.1–1.0	0.6
Mollisols	5,480	131	73	5	0.9–4.0	2.4
Spodosols	4,878	146	71	5	1.5–5.0	2.0
Alfisols	18,283	69	127	8	0.5–3.8	1.4
Ultisols	11,330	93	105	7	0.9–3.3	1.4
Oxisols	11,772	101	119	8	0.9–3.0	2.0
Misc. land	7,644	24	18	1	—	—
Total	135,215		1576	100		

[a] Organic matter may be roughly estimated as 1.7 to 2.0 times this value. The value traditionally used is 1.72. Organic nitrogen may also be estimated from organic carbon values by dividing by 12 for most soils, but see Section 12.3.
[b] Petagram = 10^{15} g.
[c] Percent on mass basis (i.e., g/100 g).
[d] These soils are too variable to suggest a typical value.
[e] Carbon stored in Gelisols is included with these soils.
Data calculated from Eswaran, et al. (1993) and Brady (1990).

What is soil organic matter (SOM)?

- Originates from plant tissue primarily and animal secondarily (soil and above ground) as well as microbial
- Three parts:

1) Living plant, animal and soil organisms

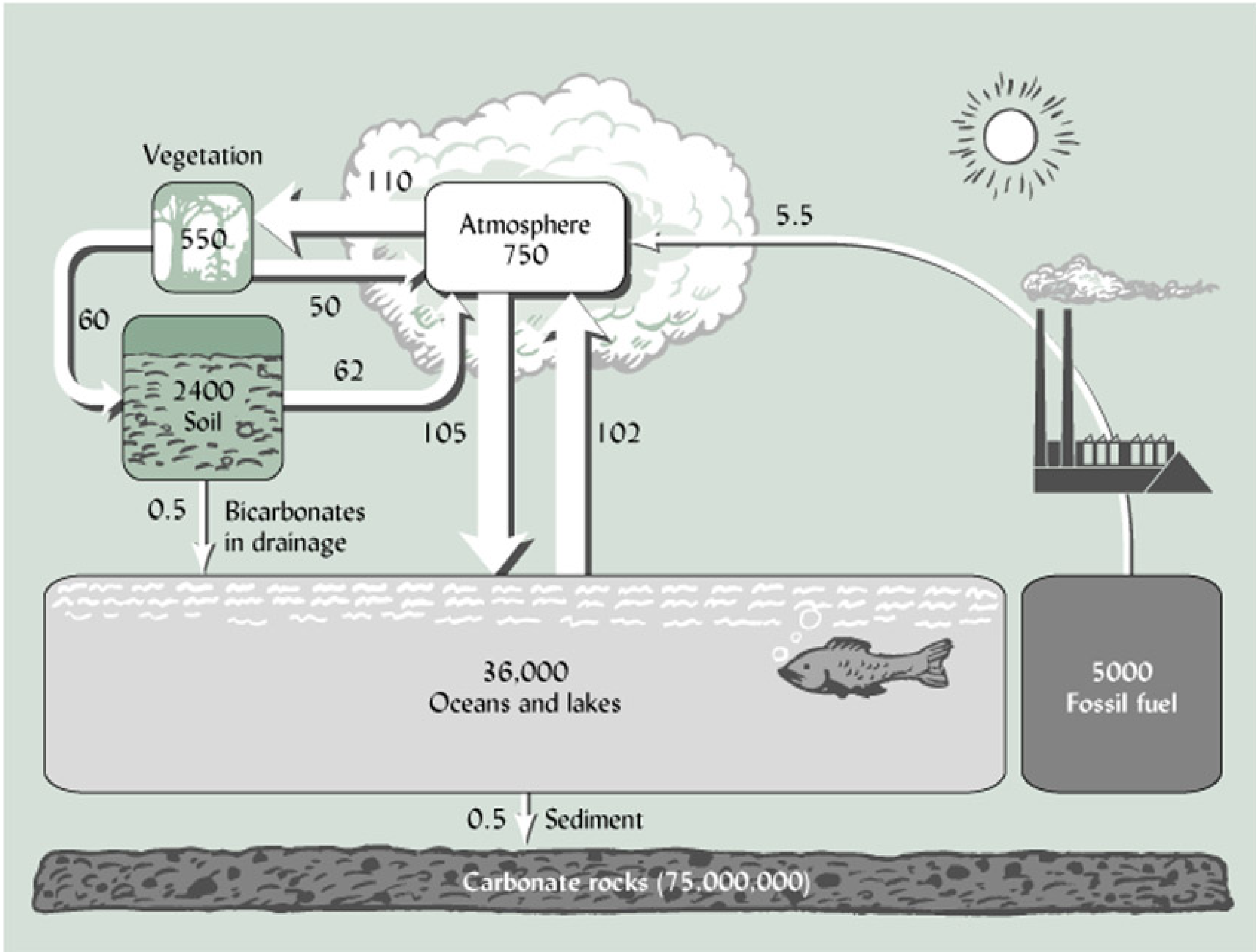
2) Dead roots and other identifiable residues

detritus

3) non-identifiable amorphous and colloidal materials = *humus*

- Contains carbon

Figure 12.1


Vegetation
550
110
Atmosphere
750
5.5
50
60
62
2400
Soil
105
102
0.5
Bicarbonates
in drainage
36,000
Oceans and lakes
5000
Fossil fuel
0.5
Sediment
Carbonate rocks (75,000,000)

Plant tissue

Rapid decomposition

Sugar, starch and simple proteins

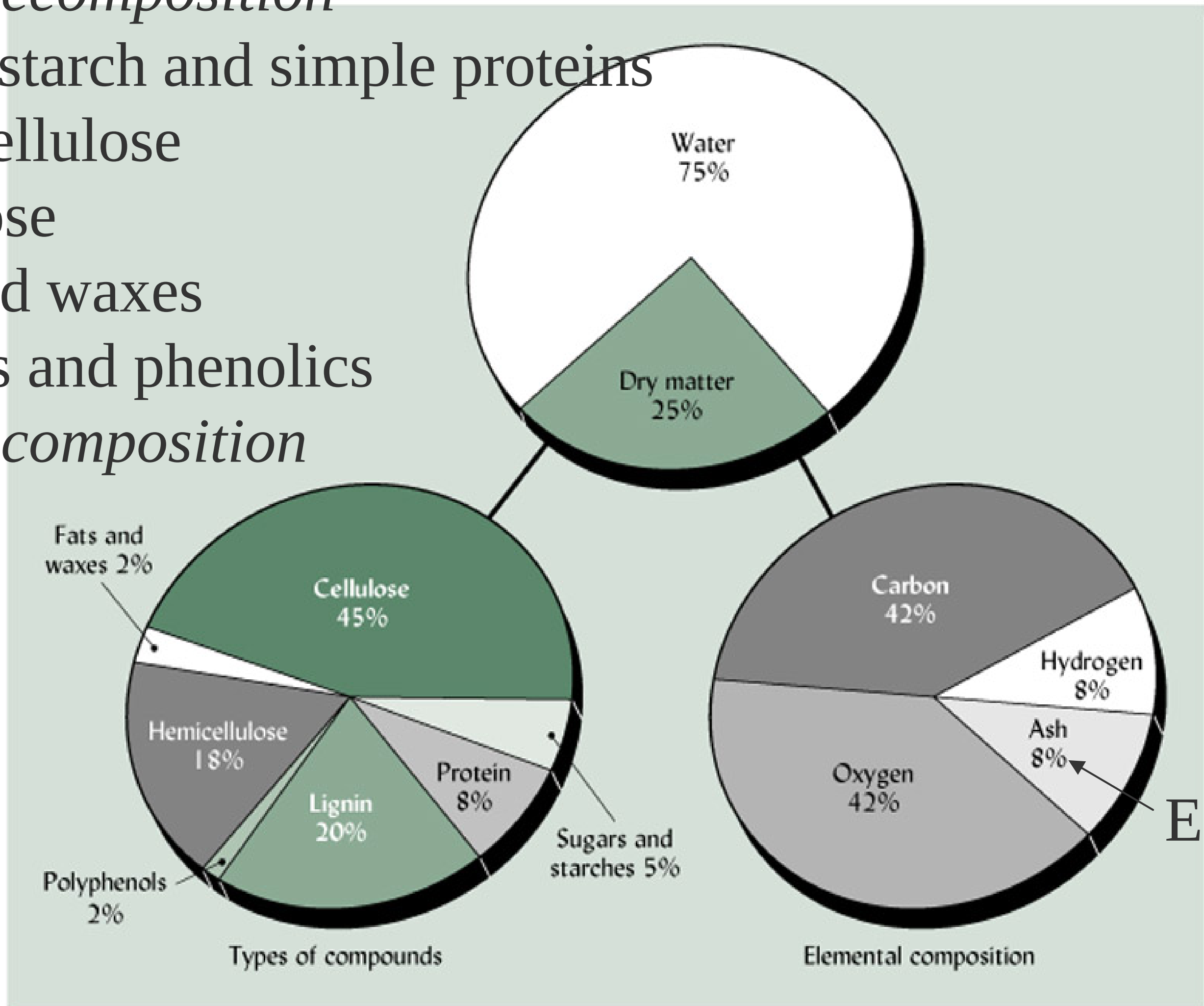
Hemicellulose

Cellulose

Fats and waxes

Lignins and phenolics

Slow decomposition



Elements

Figure 12.2

Decomposition

- Carbon compounds oxidized to CO_2
- Essential plant nutrients mineralized/immobilized depending on each element
- Resistant compounds formed (fulvic and humic acids)

Organic decay process through time

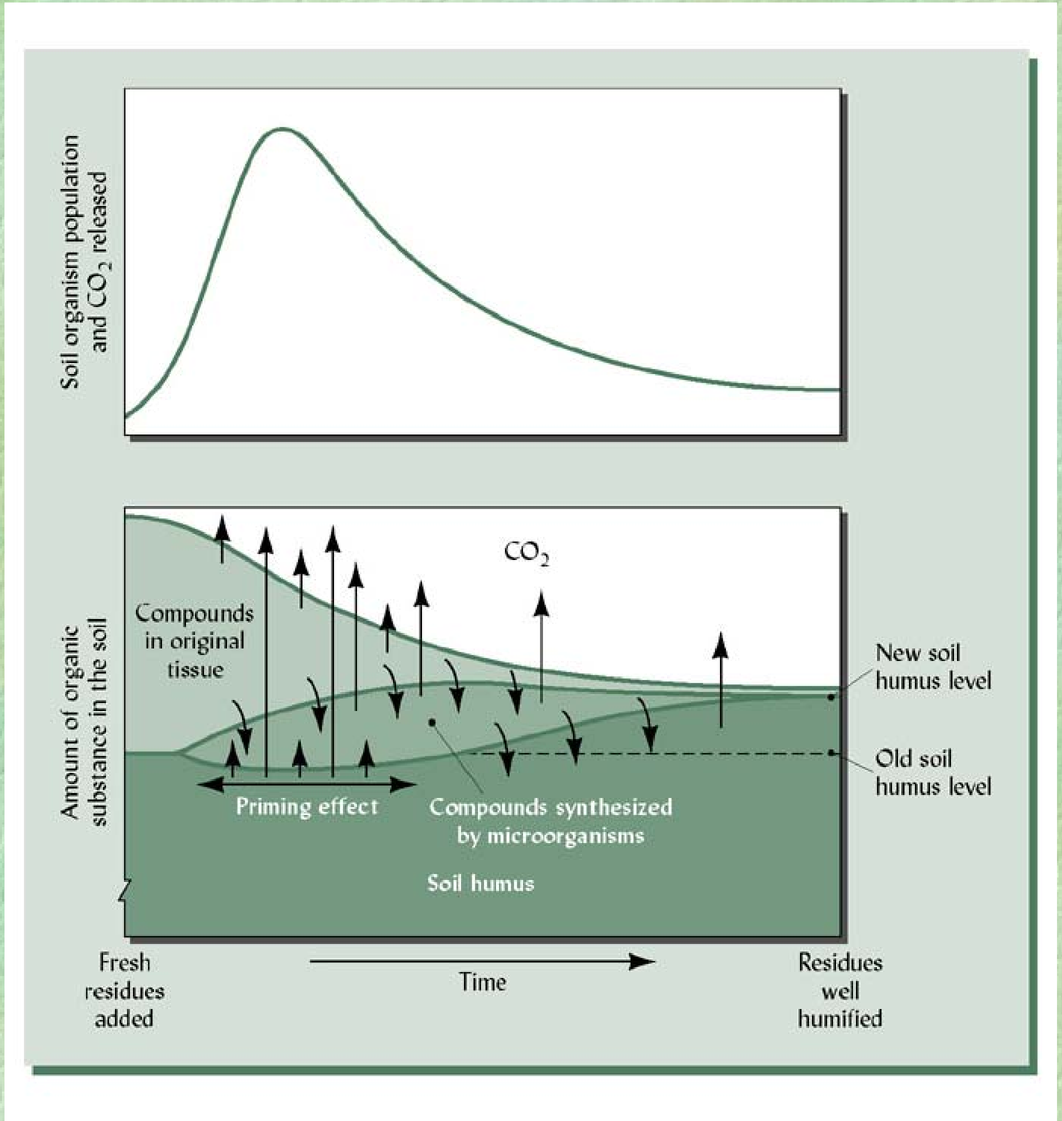


Figure 12.3

Microbial respiration peaks as microbes use up easily degradable substrates

- Small resident pop’n of active organisms (*autochthonous*)
- Fresh material stimulates group of inactive opportunistic (*zymogenous*) organisms
- Microbial pop’n at peak is 1/6 of SOM
- *Priming effect*: stimulates breakdown of resistant microorganisms
- *Mineralization* due to death of microbial pop’n due to lack of substrate and predation
    - N, S from protein breakdown
- Carbon can be chemically protected (humus) or physical protection with clay

Factors controlling decomposition and mineralization: Environmental conditions and litter quality

- Environmental conditions
  - temperature
  - moisture
  - oxygen
- Litter quality
  - C/N ratio
  - content of resistant compounds: lignins and phenols

Why is C/N ratio important

- Plants have higher C/N ratio in tissues than bacteria and fungi need
- Plant tissue 10C:1N to 600:1 but bacteria and fungi ratio 5:1 to 10:1 (but 2/3 of C is respired so optimum is 25-30:1)
- Microbes are fed first, then whatever is left is available to plants
- Microbes need more N than plants do so there is a competition for N which may lead to a “nitrate depression period” where scare N not available to plants

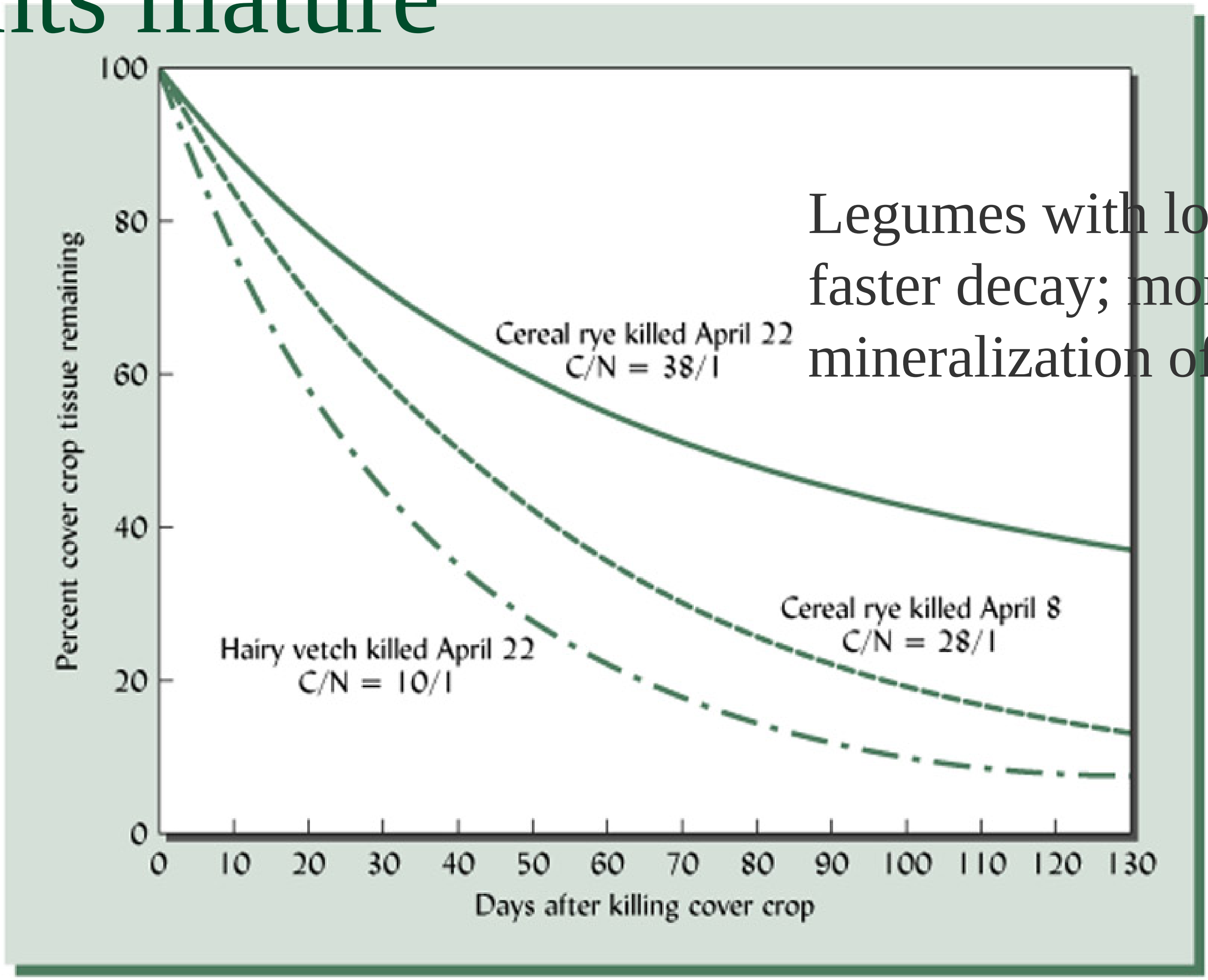
C/N ratio

TABLE 12.2 **Typical Carbon and Nitrogen Contents and C/N Ratios of Some Organic Materials Commonly Associated with Soils**

Organic material	*% C*	*% N*	*C/N*
Spruce sawdust	50	0.05	600
Hardwood sawdust	46	0.1	400
Newspaper	39	0.3	120
Wheat straw	38	0.5	80
Paper mill sludge	54	0.9	61
Corn stover	40	0.7	57
Sugarcane trash	40	0.8	50
Rye cover crop, anthesis	40	1.1	37
Bluegrass from fertilized lawn	37	1.2	31
Rye cover crop, vegetative stage	40	1.5	26
Mature alfalfa hay	40	1.8	25
Rotted barnyard manure	41	2.1	20
Broccoli residues	35	1.9	18
Finished household compost	30	2.0	15
Young alfalfa hay	40	3.0	13
Hairy vetch cover crop	40	3.5	11
Digested municipal sewage sludge	31	4.5	7
Soil microorganisms			
Bacteria	50	10.0	5
Actinomycetes, nematodes	50	8.5	6
Fungi	50	5.0	10
Soil organic matter			
Spodosol O horizon	50	0.5	90
Average forest O horizons	50	1.3	45
Average forest A horizons	50	2.8	20
Tropical evergreen litter	50	2.0	25
Mollisol Ap horizon	56	4.9	11
Average B horizon	46	5.1	9

Data calculated from many sources.

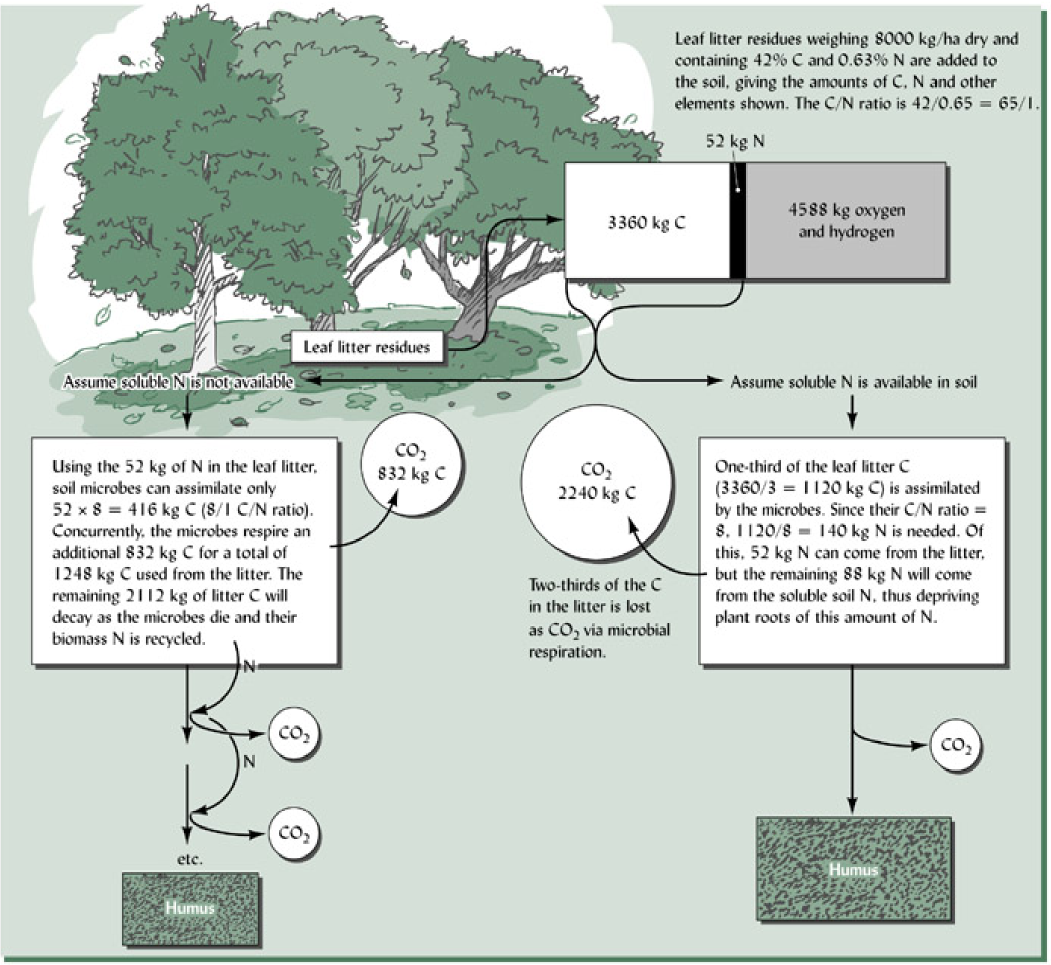
Higher C/N ratio as cover crop plants mature



Legumes with lower C/N; faster decay; more net mineralization of N

Figure 12.4

Figure 12.5



Leaf litter residues weighing 8000 kg/ha dry and containing 42% C and 0.63% N are added to the soil, giving the amounts of C, N and other elements shown. The C/N ratio is 42/0.65 = 65/1.
52 kg N
3360 kg C
4588 kg oxygen and hydrogen
Leaf litter residues
Assume soluble N is not available
Assume soluble N is available in soil
Using the 52 kg of N in the leaf litter, soil microbes can assimilate only 52 × 8 = 416 kg C (8/1 C/N ratio). Concurrently, the microbes respire an additional 832 kg C for a total of 1248 kg C used from the litter. The remaining 2112 kg of litter C will decay as the microbes die and their biomass N is recycled.
CO_2 832 kg C
CO_2 2240 kg C
Two-thirds of the C in the litter is lost as CO_2 via microbial respiration.
One-third of the leaf litter C (3360/3 = 1120 kg C) is assimilated by the microbes. Since their C/N ratio = 8, 1120/8 = 140 kg N is needed. Of this, 52 kg N can come from the litter, but the remaining 88 kg N will come from the soluble soil N, thus depriving plant roots of this amount of N.
N
CO_2
N
CO_2
etc.
Humus
CO_2
Humus

Lower C/N ratio less nitrate depression
C/N of 20 optimal for plant nutrient uptake

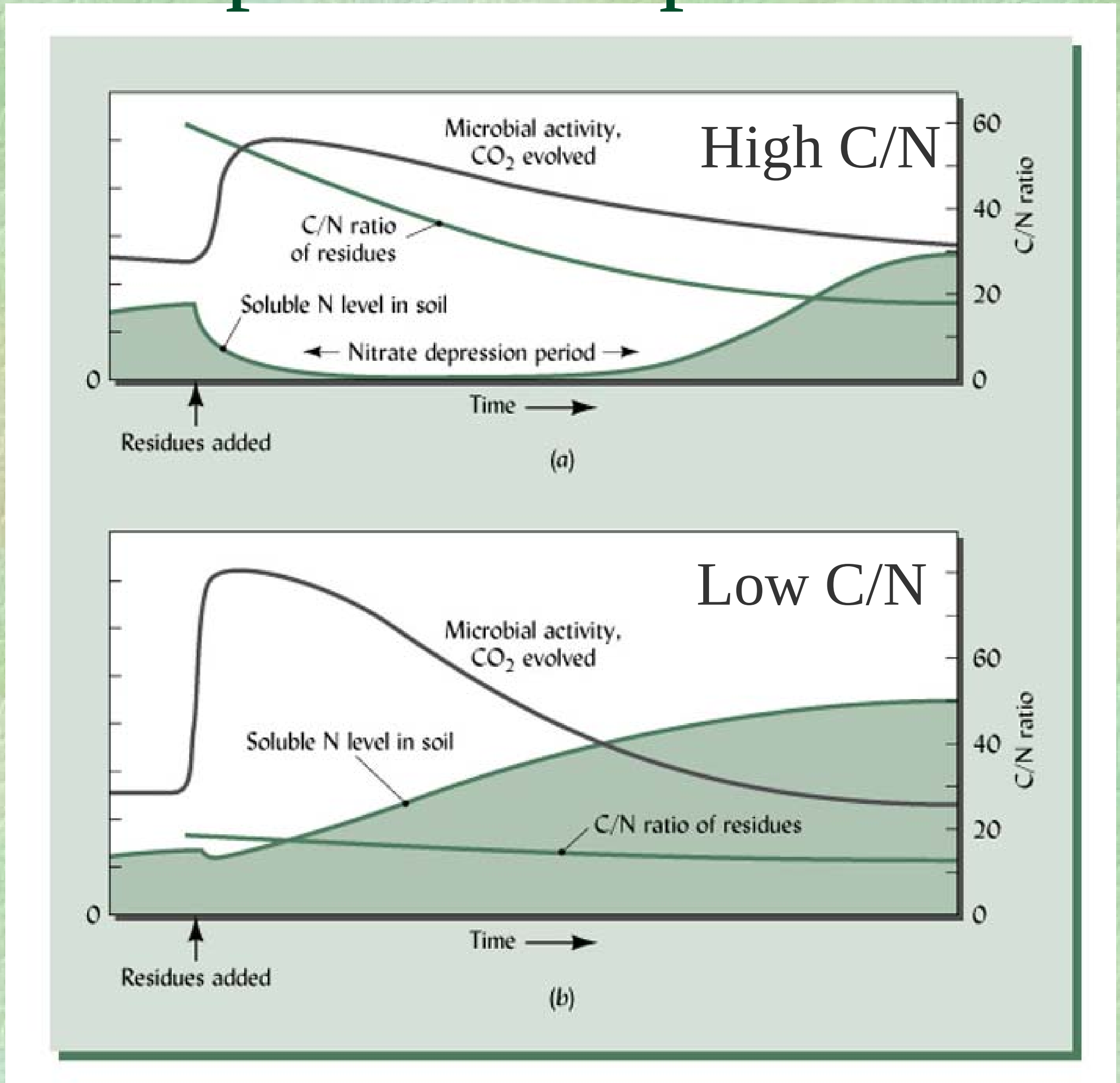


Figure 12.6

N release of nematodes feeding at higher C/N ratio is equivalent to a lower C/N ratio

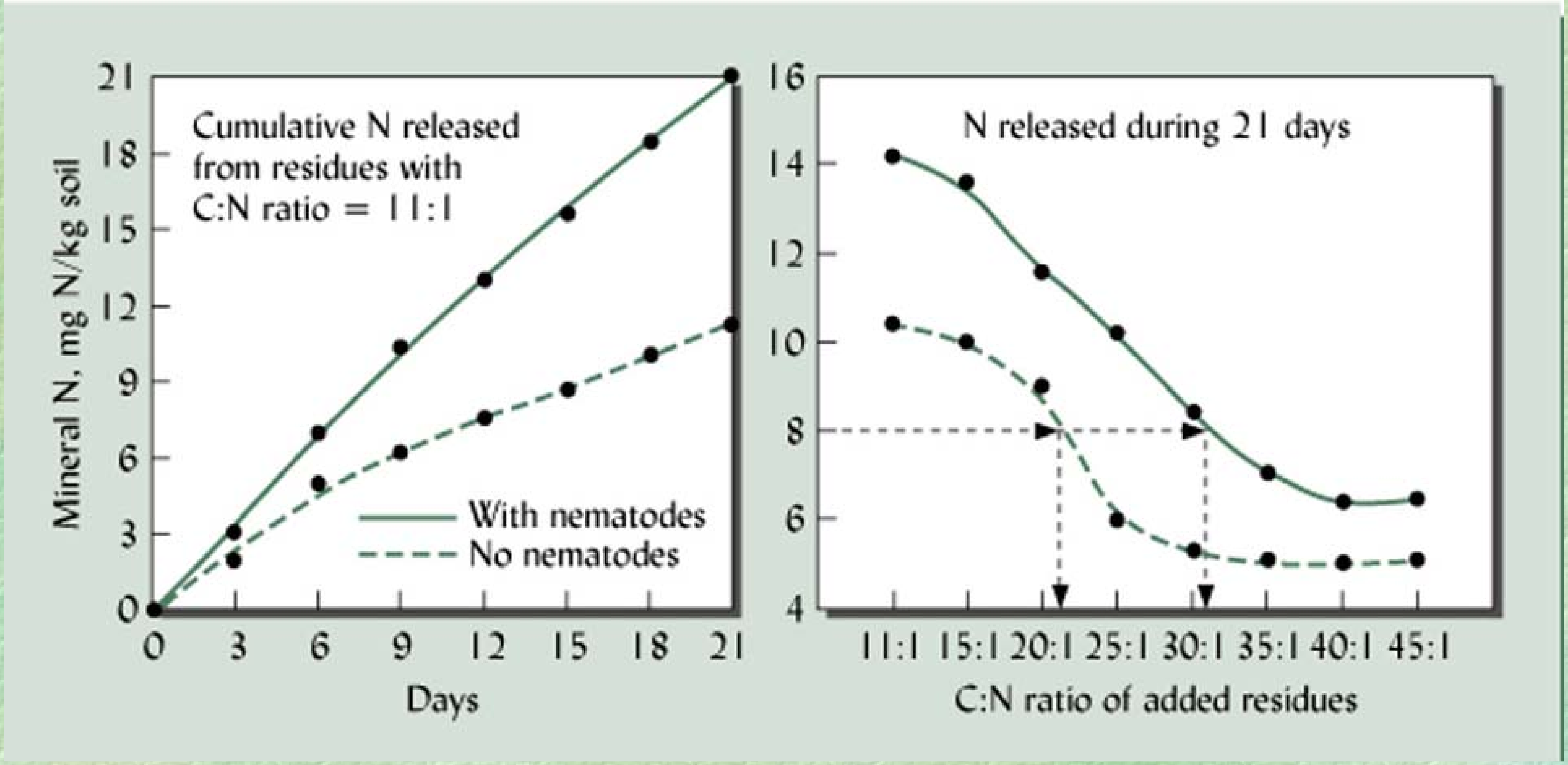


Figure 12.7

Polyphenols decrease decomposition rate

Gliricidia

ation to the Lignin Content, Polyphenol Content and C/N Ratio

igs) of three common agroforestry tree species and afterharvest residues of two
rate of 5 Mg/ha to an Oxic Paleudult in a humid tropical region of Nigeria.
polyphenols all contribute to high litter quality and high speed of decomposition.
polyphenol content can be seen by comparing Gliricidia *to* Leucaena.

Plant species	*Plant parts*	*Lignin, %*	*Polyphenols, %*	*C/N*	*Decomposition constant,[a] k/week*	*Litter quality*
Gliricidia sepium	Prunings	12	1.6	13	0.255	High
Leucaena leucocephala	Prunings	13	5.0	13	0.166	Medium–high
Oryza sativa	Straw	5	0.6	42	0.124	Medium
Zea mays	Stover	7	0.6	43	0.118	Medium
Dactyladenia barteri	Prunings	47	4.1	28	0.011	Low

[a] As each type of residue decomposed during a 14-week season, researchers periodically determined the prop
remaining. The decomposition rate *k* was determined from the equation $Y = e^{-kt}$, in which *e* is the base of natura
fore, the larger the decomposition constant *k*, the faster the decomposition.
Data selected from Tian, et al. (1992 and 1995).

Brady and Weil Table 12.3

Leucaena

Quality depends both of C/N and lignin and polyphenols

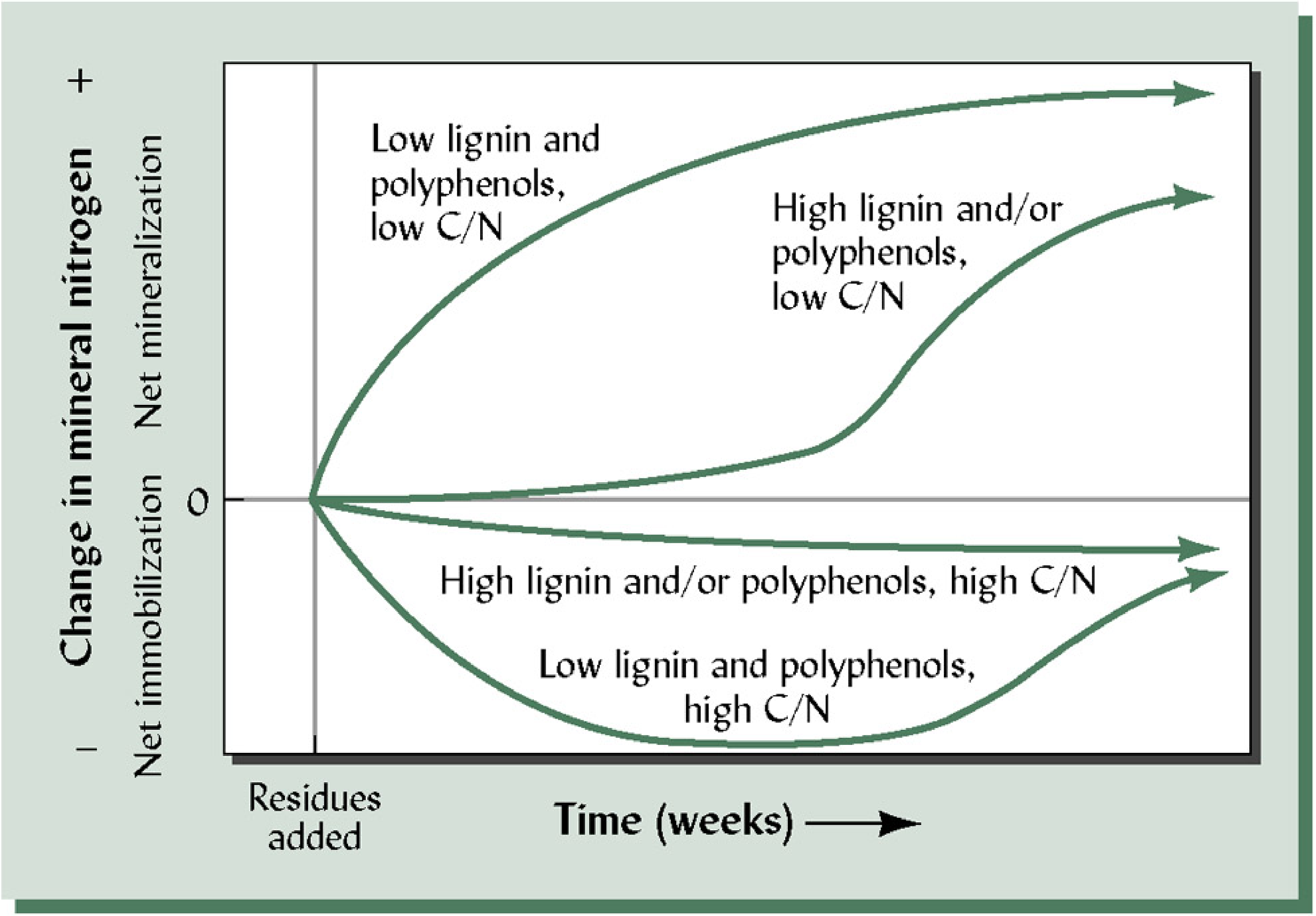


Figure 12.8

How SOM influences soil properties!

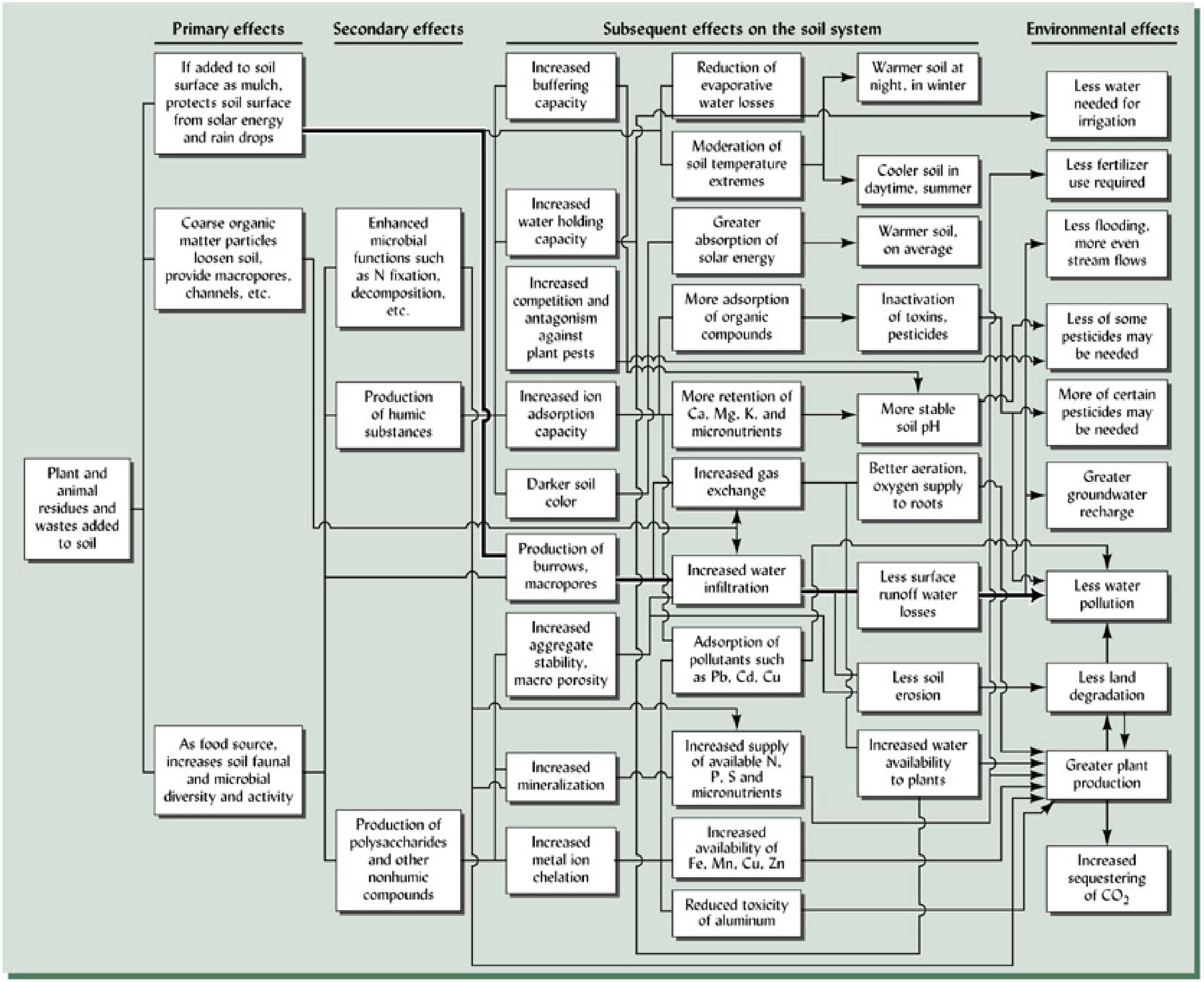


Figure 12.15

Composting at various scales

(a) (b)

Composting: practice of creating humus-like organic material outside of the soil

Figure 12.13

Figure 12.11

Aerobic composting process

Three steps:

- *Mesophyllic*- pre-peak and less than 40º C
- *Thermophyllic*- peak of microbial activity and heat 50-75º C
- *Mesophyllic* or curing stage-less than 40º C
  actinomycetes and fungi dominate, recolonization by thermophyllic organisms- plant growth stimulating, orgs antagonistic to plant pathogens

Benefits of composting

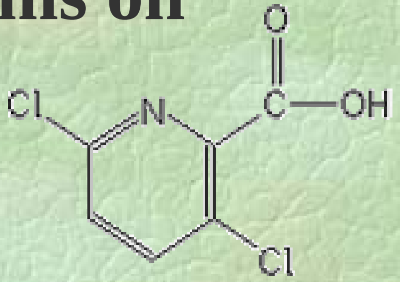
- Safe storage
- Easier handling
- N competition avoidance
- N stabilization: co-composting of high and low C/N ratio materials
- Partial sterilization- weed seeds and pathogens
- Detoxification, but see chlopyralid
- Disease suppression

Clopyralid (pyradine herbicide)

especially used in grasses for thistle control

Acute toxicity not available, not likely carcinogen, potential ground water contaminant, much not known

50-0 ppb symptoms on pinto bean



50 ppb

wsu.gov/compost

Fig 12.12 Three stages of compost

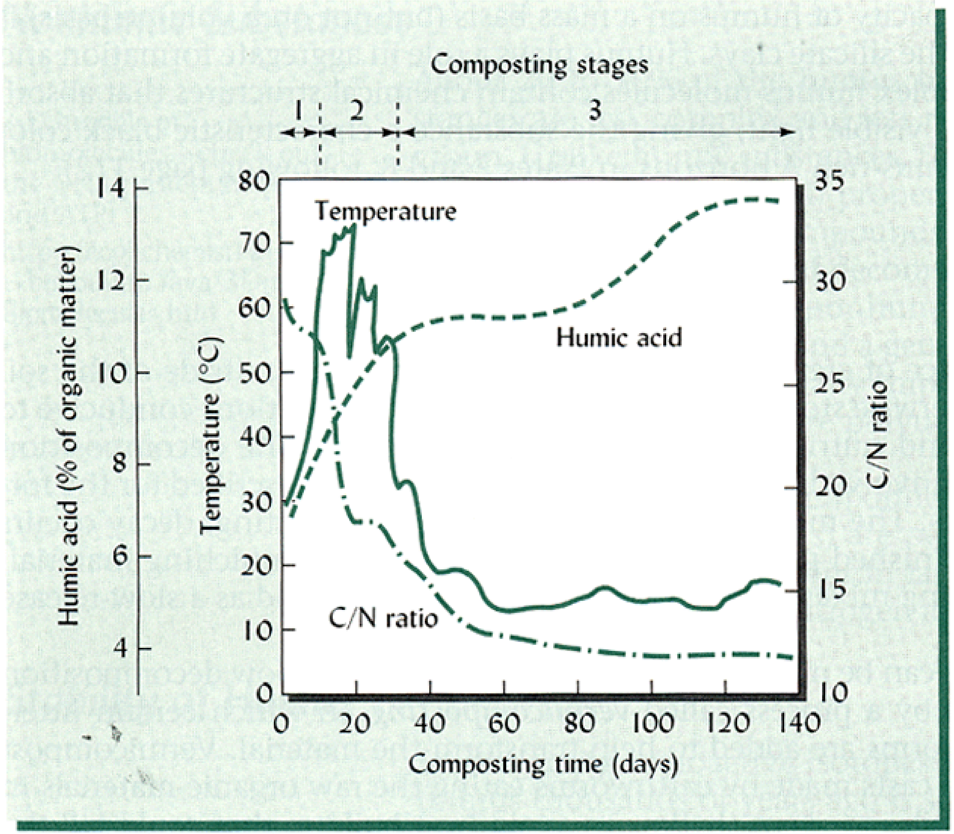
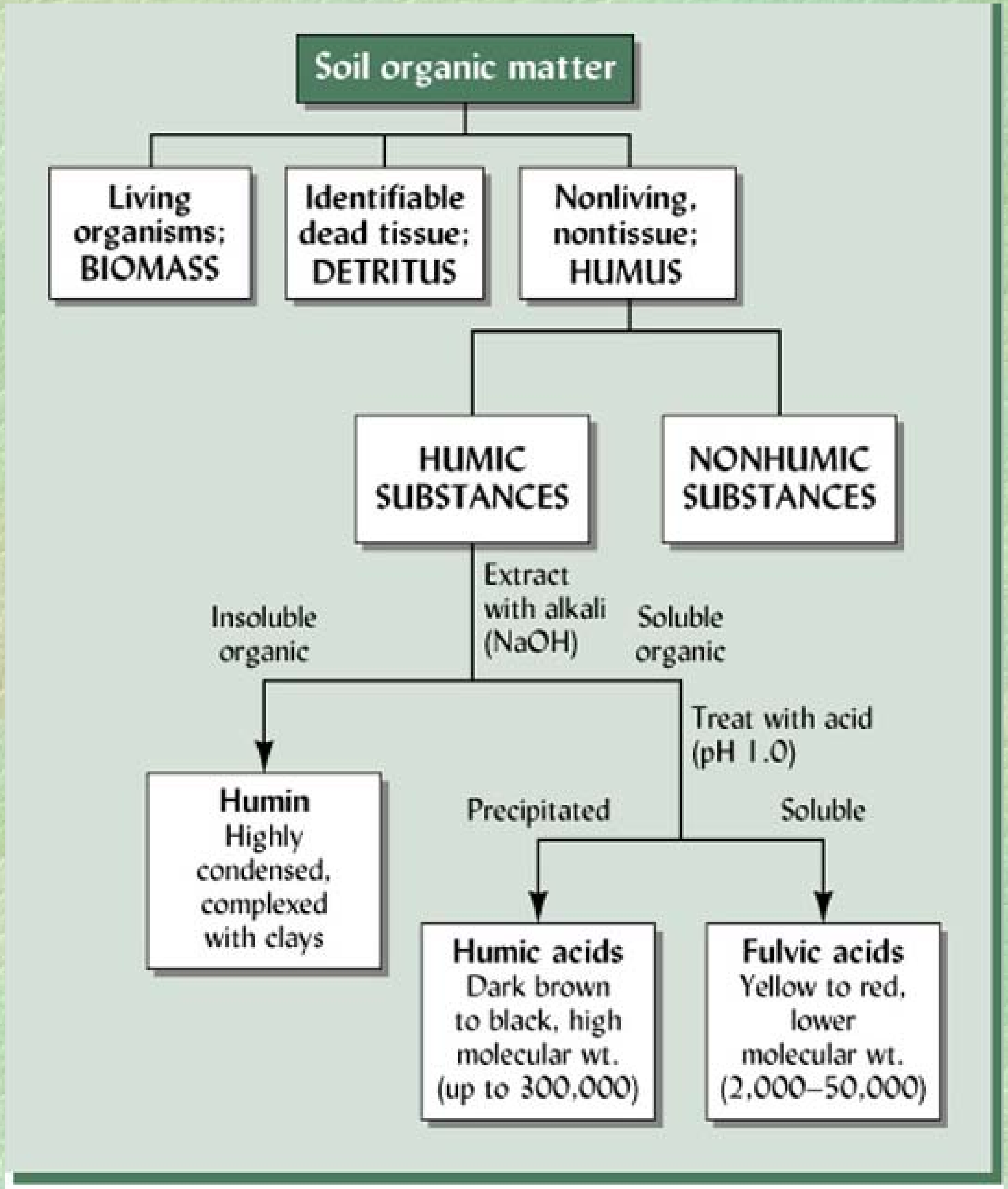


FIGURE 12.12 Changes in the temperature, C/N ratio, and humic acid contents of the organic matter during the production of compost from municipal solid wastes (MSW). The compost was turned (mixed for aeration) once a week for the first 49 days and once in two weeks thereafter. The stages of the compost process are: (1) initial mesophilic stage, (2) thermophilic stage, and (3) final mesophilic or curing stage. See text for explanation of the composting process. [Data redrawn from Chefetz, et al. (1996)]

B&W, (2002), <u>The Nature & Properties of Soils</u>



Soil organic matter
Living organisms; BIOMASS
Identifiable dead tissue; DETRITUS
Nonliving, nontissue; HUMUS
HUMIC SUBSTANCES
NONHUMIC SUBSTANCES
Extract with alkali (NaOH)
Insoluble organic
Soluble organic
Treat with acid (pH 1.0)
Precipitated
Soluble
Humin
Highly condensed, complexed with clays
Humic acids
Dark brown to black, high molecular wt. (up to 300,000)
Fulvic acids
Yellow to red, lower molecular wt. (2,000–50,000)

Figure 12.9

Most of C released as CO_2

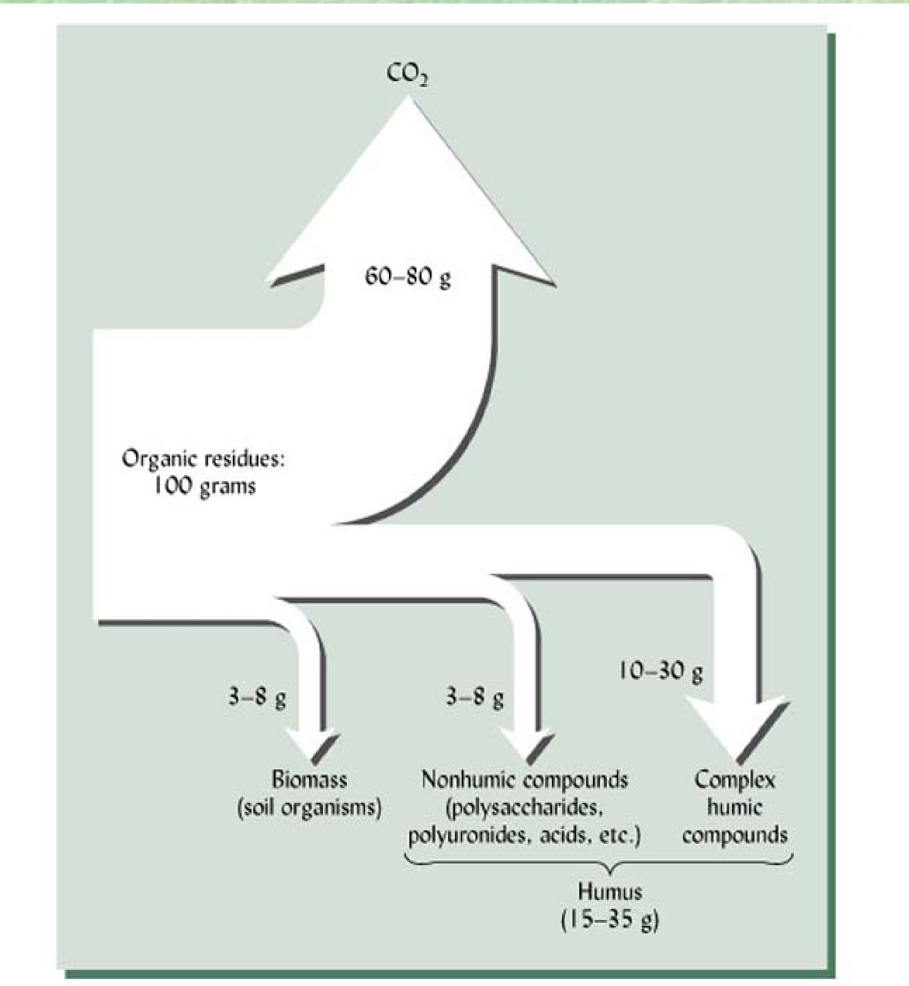


Figure 12.10

Humus consist of:

- Non-humic substances (20-30% of SOM): synthesized by microbes
- Humic substances (60-80% of SOM)
  - fulvic acids: half life is 10-50 years
  - *humic acids:* half life is centuries
  - *humin:* highest mw, most resistant to decay

Fig 12.16 Three pools of C after the CENTURY model

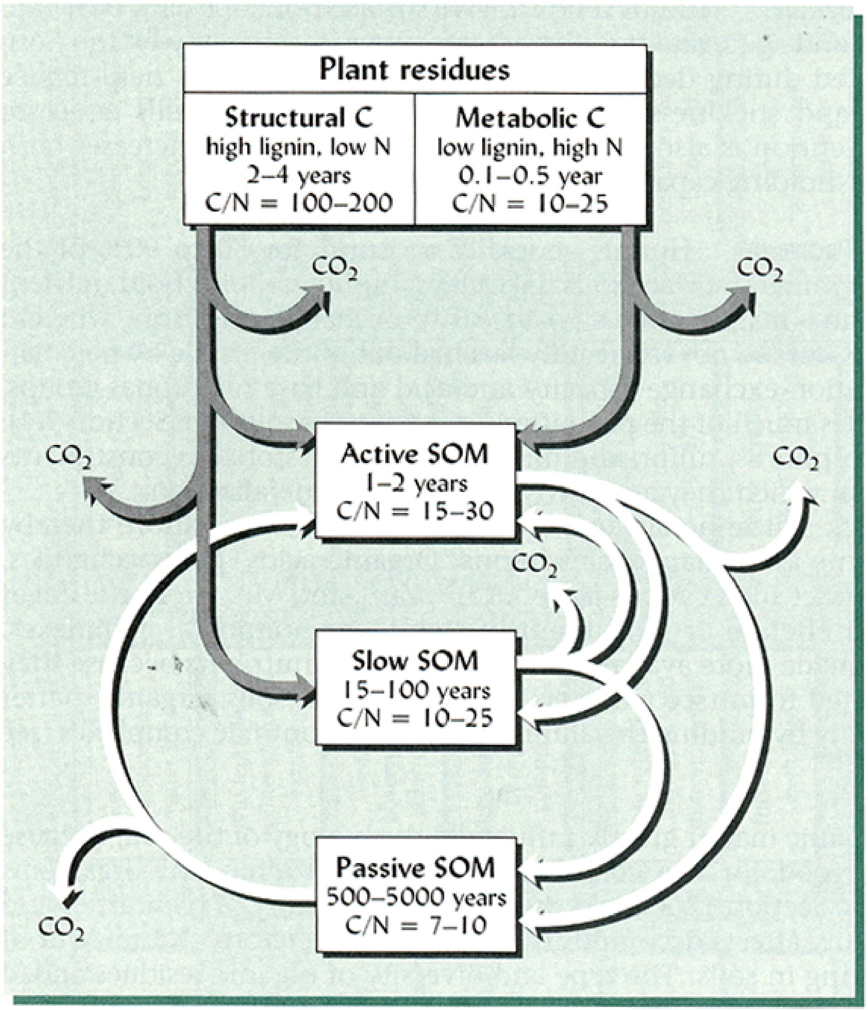


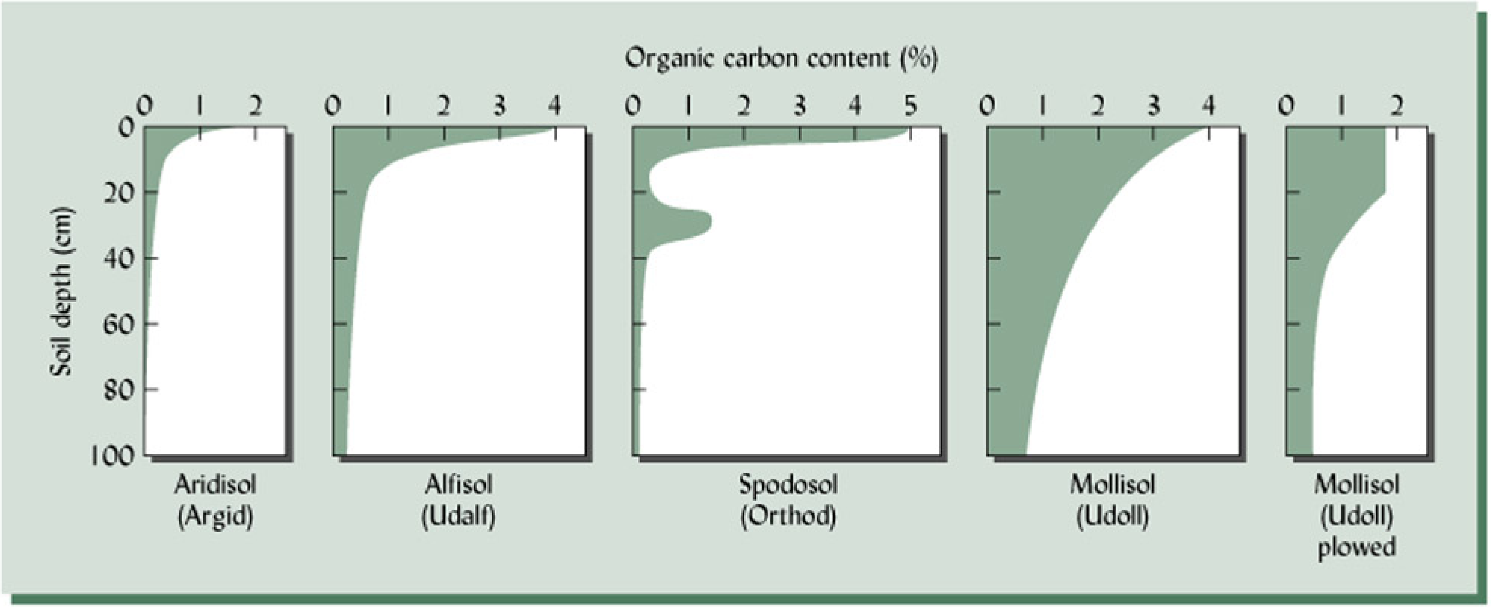
FIGURE 12.16 A conceptual model that recognizes various pools of soil organic matter (SOM) differing by their susceptibility to microbial metabolism. Models that incorporate *active, slow,* and *passive* fractions of soil organic matter have proven very useful in explaining and predicting real changes in soil organic matter levels and in attendant soil properties. Note that microbial action can transfer organic carbon from one pool to another. For example, when the nonhumic substances and other components of the active fraction are rapidly broken down, some resistant, complex by-products may be formed, adding to the slow and passive fractions. Note that all these metabolic changes result in some loss of carbon from the soil as CO_2. [Adapted from Paustian, et al. (1992)]

B&W, (2002), The Nature & Properties of Soils

What determines soil organic carbon (SOC) of soil?

- Organic matter is 50-58% C
- SOC is more precisely measured

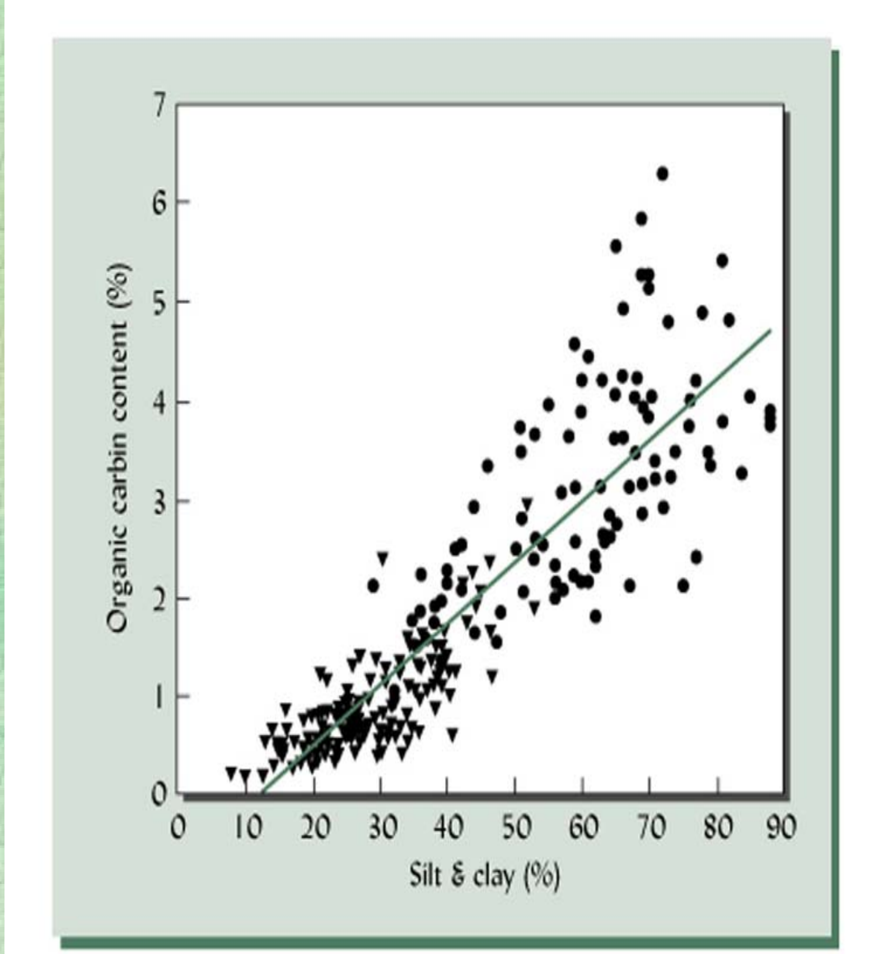
Native organic carbon differs in different soil type



Greater SOC when developed under grassland (Mollisol)

Figure 12.19

Soil texture: Clay holds SOM



Why?

1) Produce more plant biomass
2) Less well aerated
3) Protected clay-humus complexes

Figure 12.22

Fig 12.21 Native US SOM

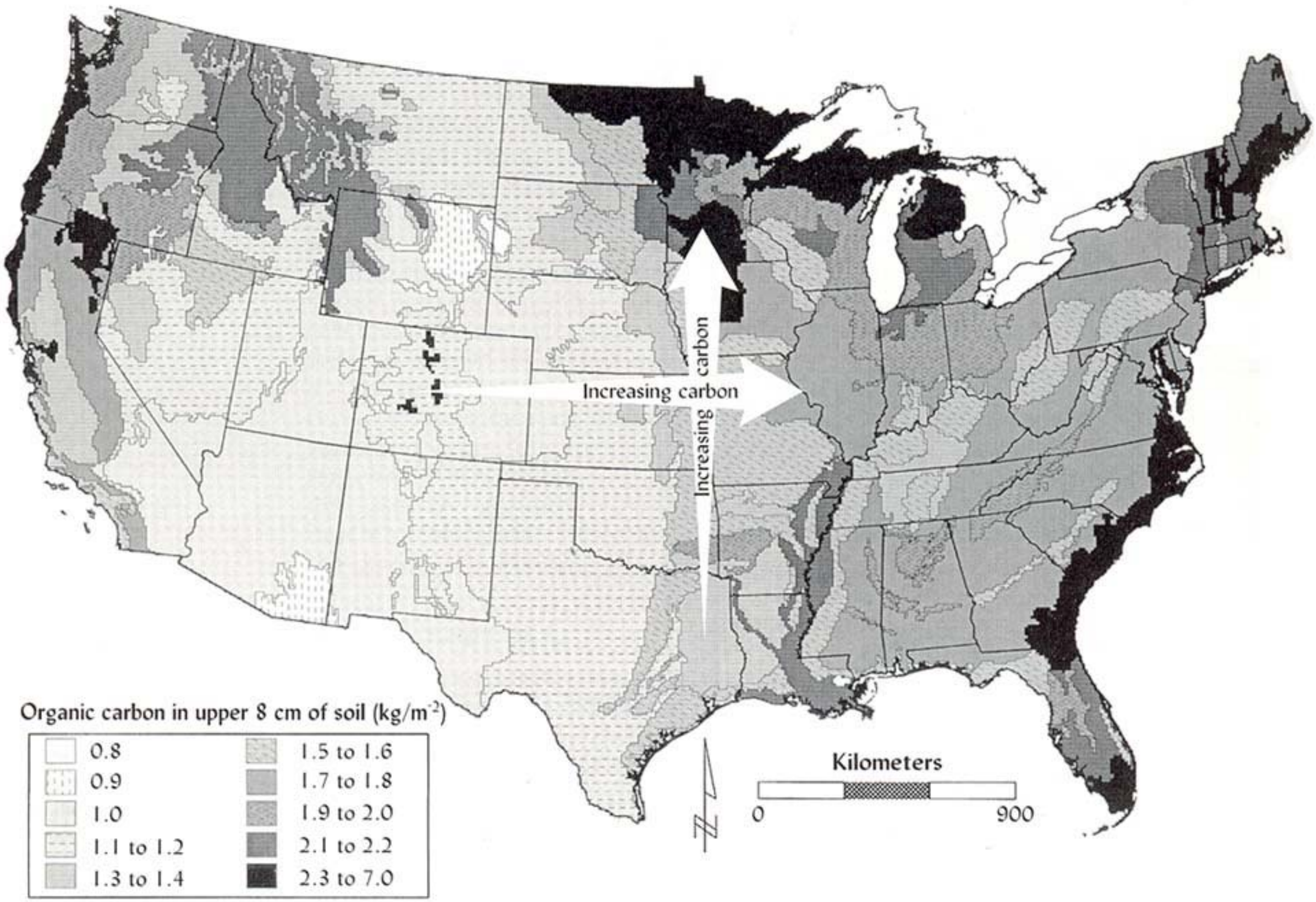
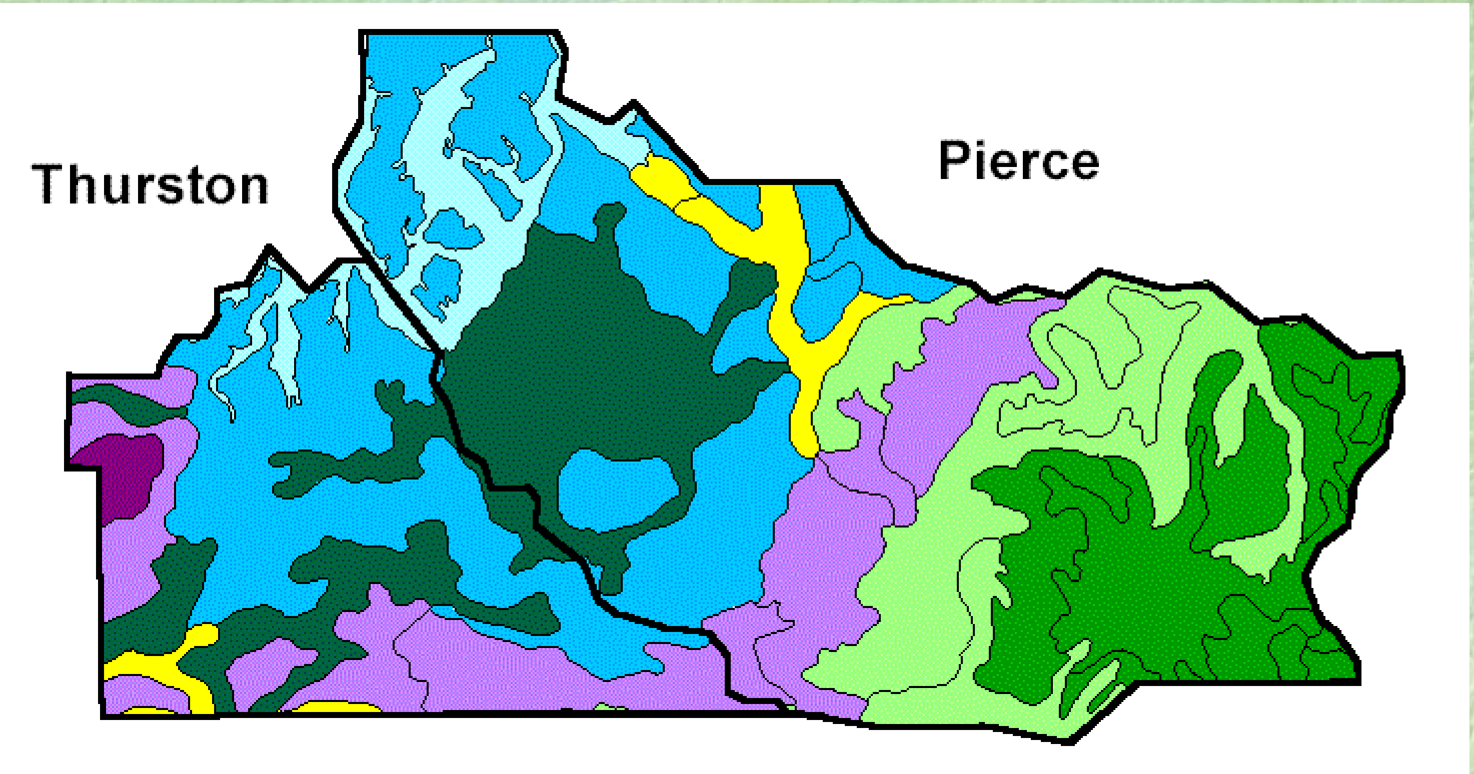


FIGURE 12.21 Influence of mean annual temperature and precipitation on organic matter levels in soils and on the difficulty of sustaining the soil resource base. The large white arrows on the map indicate that in the North American Great Plains region, soil organic matter increases with cooler temperatures 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.]

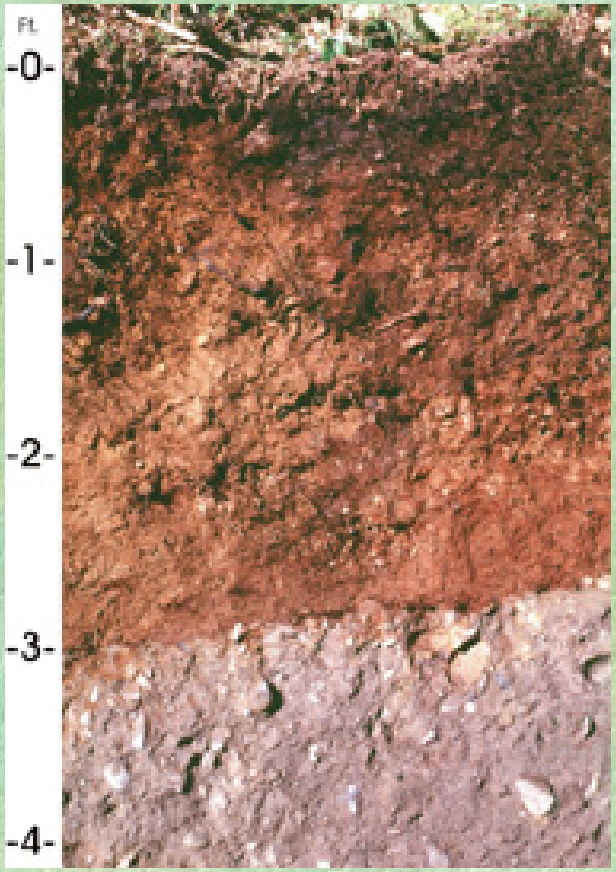
B&W, (2002), The Nature & Properties of Soils

Thurston Co soils



Blue- entisol (till influenced by alluvial ash);
Dark green is volcanic ash
Ash soils are high in SOM, bound by clays

WA State Soil Profile: Andisol



- Tokul Soil Profile
- Named after Tokul Creek in King CO.
- Common on W slope of Cascades- 1M acres
- High in OM
- Productive forest soil
- Organic matter layer, then loam from ash over cemented glacial till

Loss of active and slow pools from native to cultivated

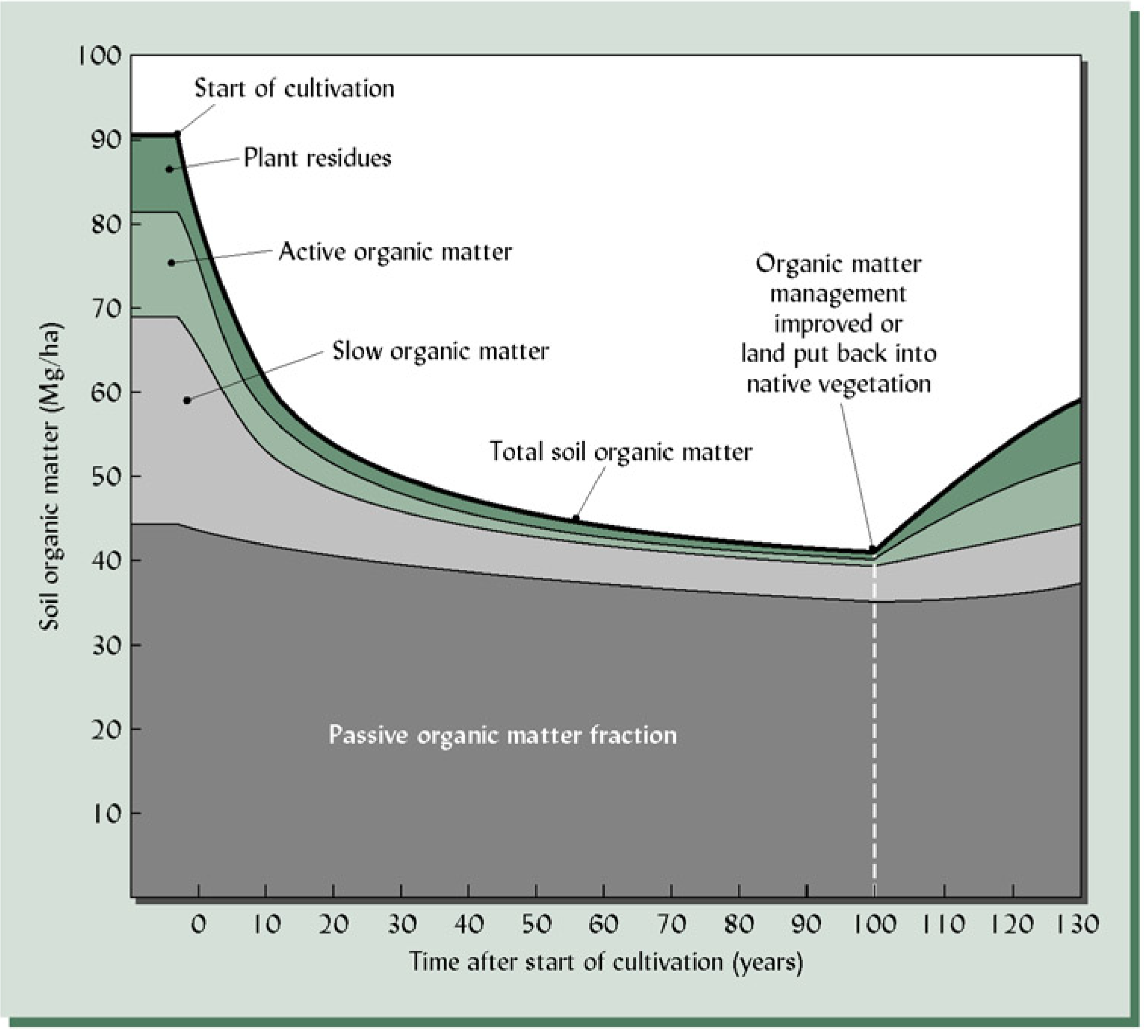
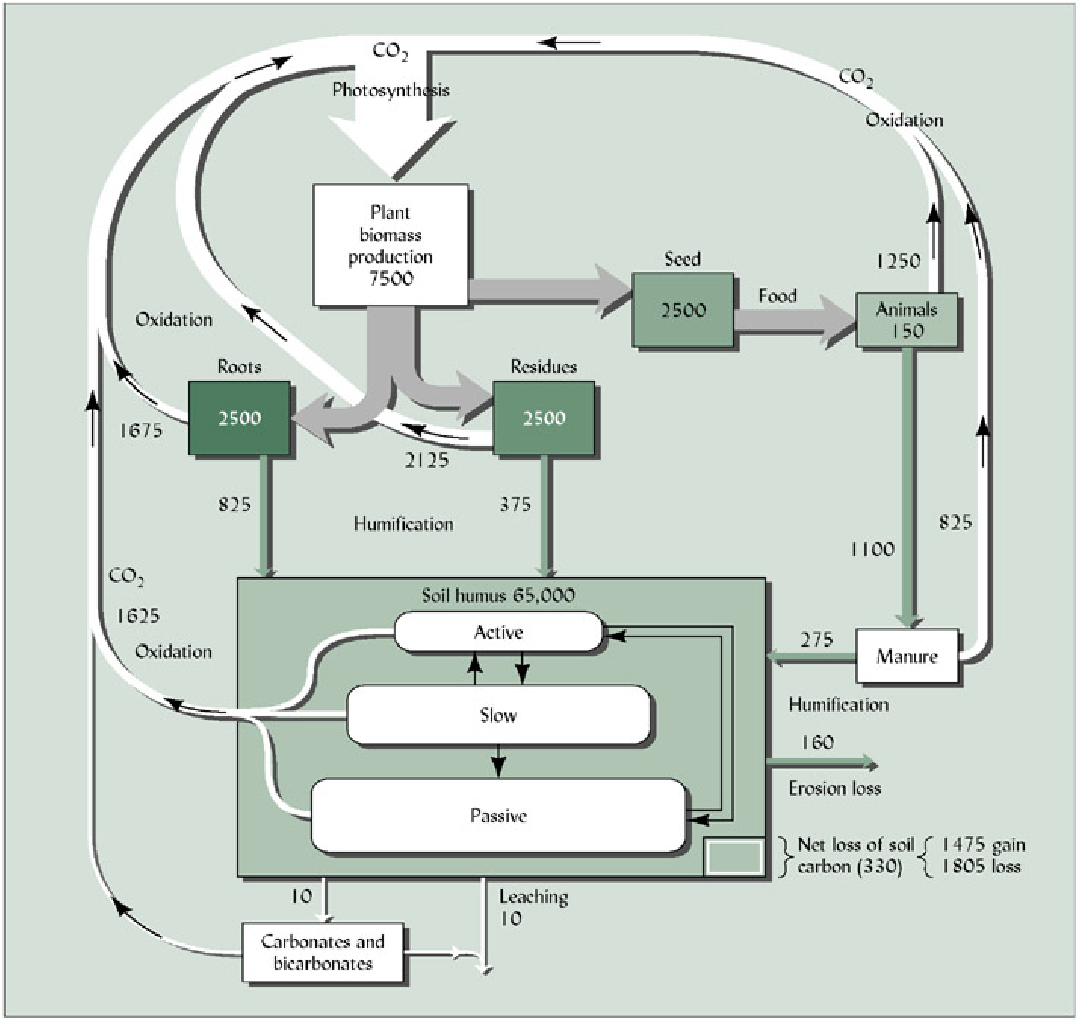


Figure 12.17

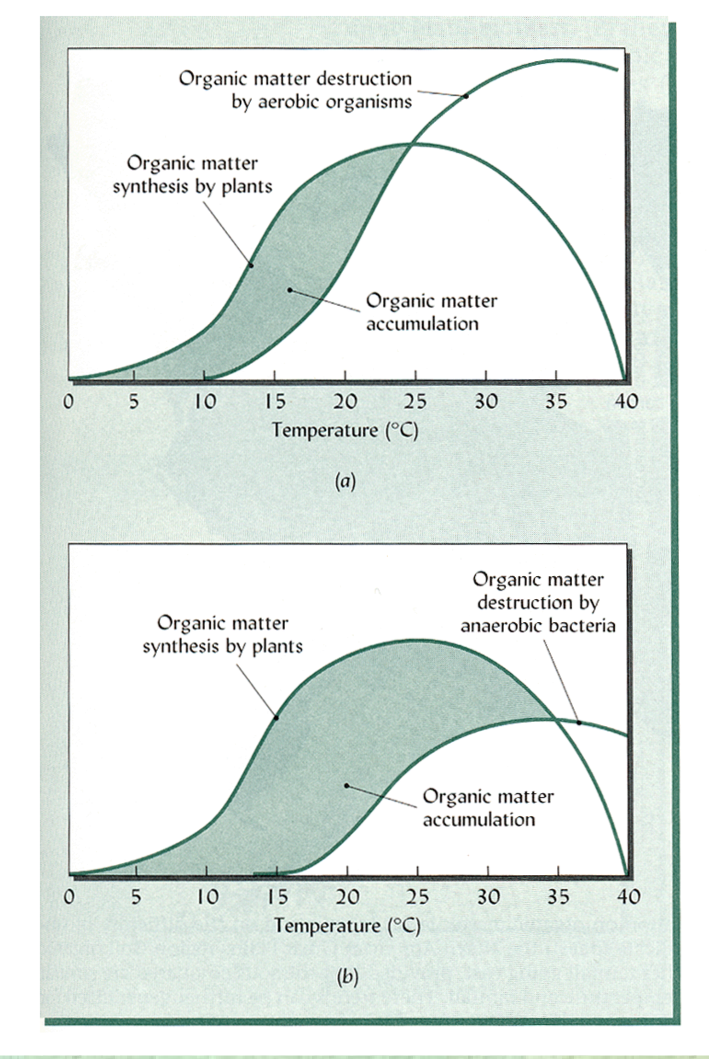
Effects of Management

Figure 12.18



C cycling in a corn agroecosystem: net loss of 0.5%/yr of C stored in soil's humus

Fig 12.20 Temperature and access to O_2 determine accumulation of SOC



- 2-3x increase in SOM for every 10°C decrease in temperature
- Implications for positive feedback loop for global warming

Poor drainage leads to accumulation of SOC

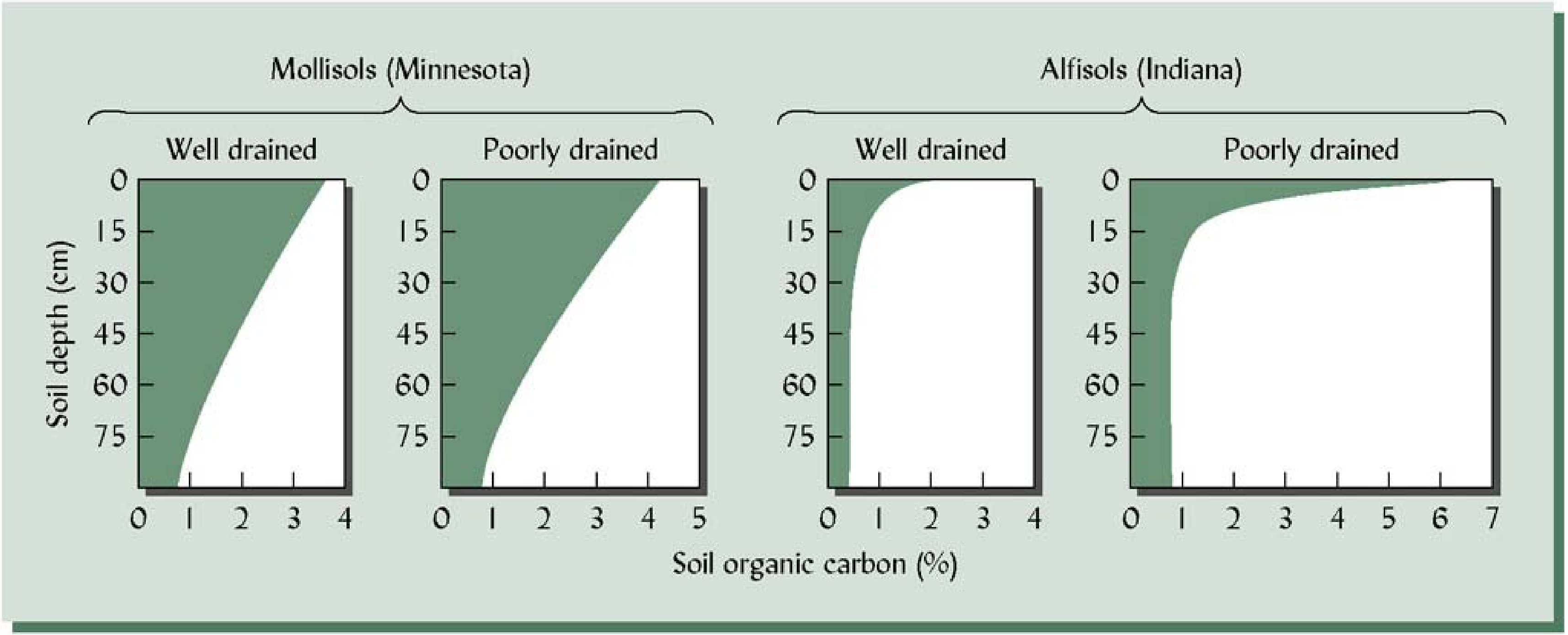


Figure 12.23

Histosols can be oxidized when drained

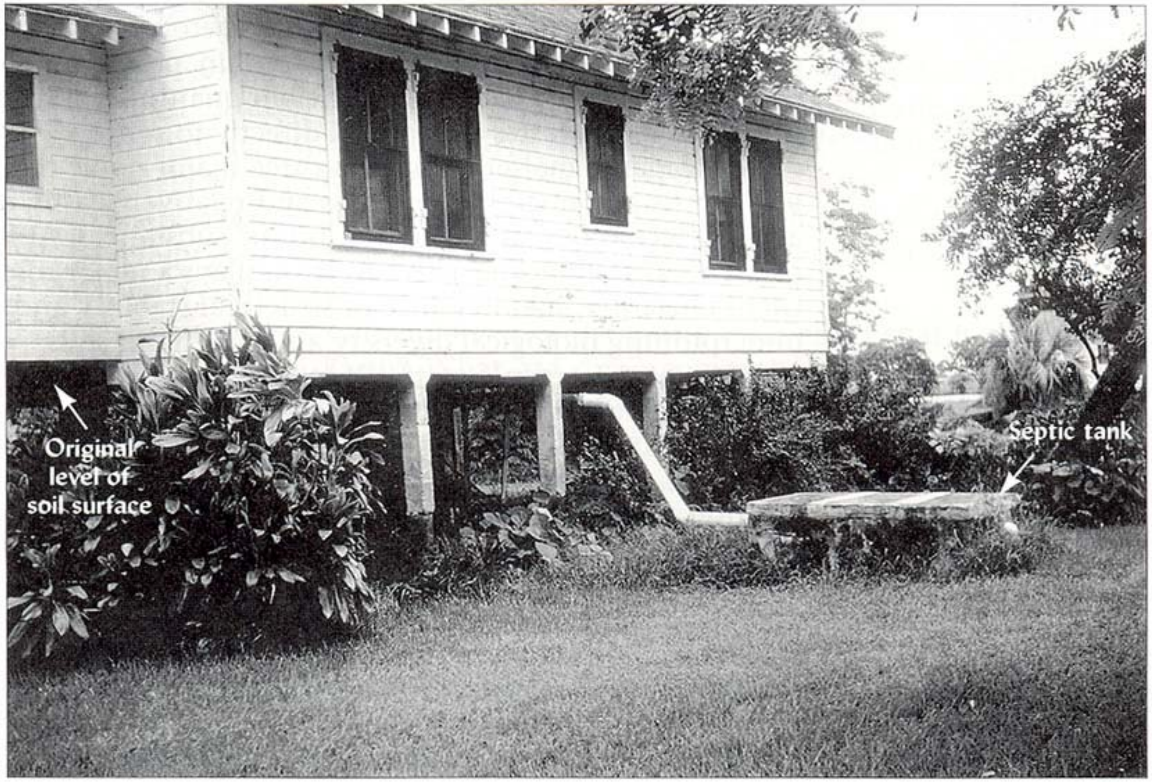
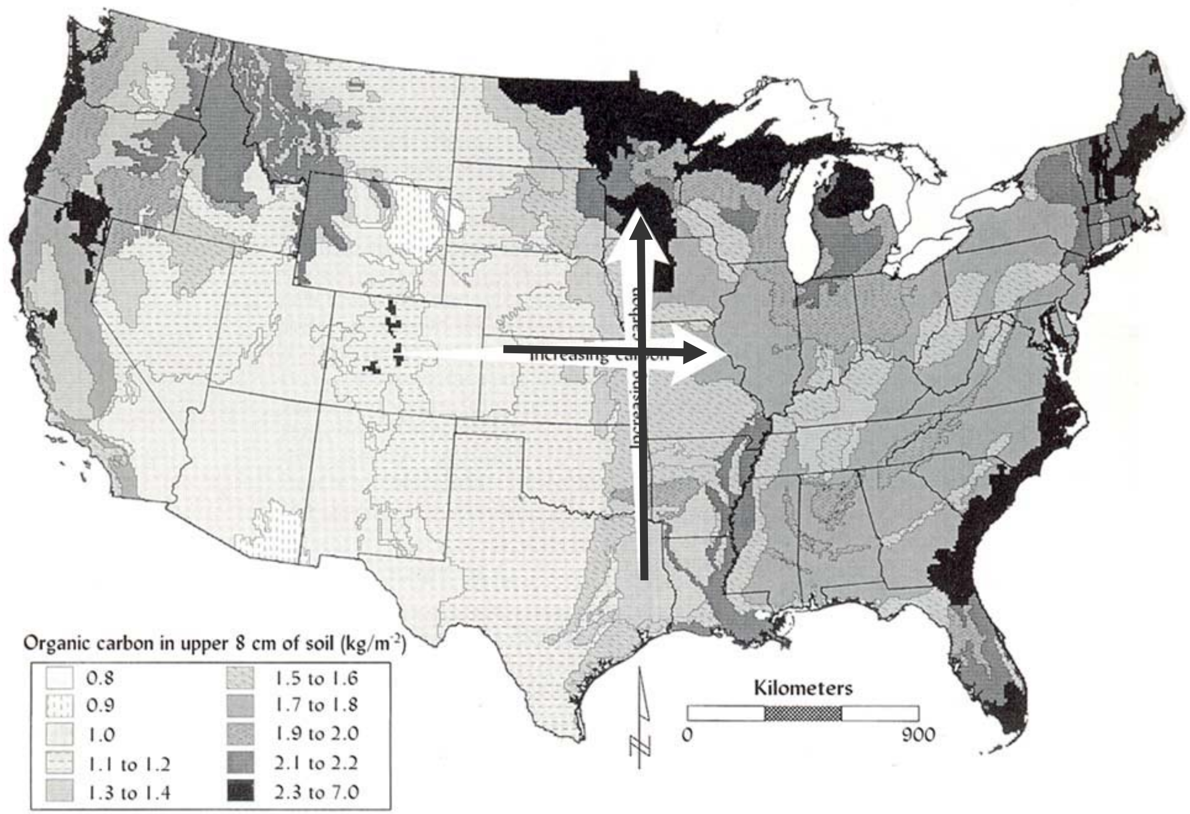


FIGURE 12.32 Soil subsidence due to rapid organic matter decomposition after artificial drainage of Histosols in the Florida Everglades. The house was built at ground level, with the septic tank buried about 1 m below the soil surface. Over a period of about 60 years, more than 1.2 m of the organic soil has "disappeared." The loss has been especially rapid because of Florida's warm climate, but artificial drainage that lowers the water table and continually dries out the upper horizons is an unsustainable practice on any Histosol. (Photo courtesy of George H. Snyder, Everglades Research and Education Center, Belle Glade, Fla.)

Brady & Weil, The Nature & Properties of Soils (2002)

Fig 12.21 Native US SOM: More precipitation greater SOC



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B&W, (2002), The Nature & Properties of Soils

Maintaining/increasing SOM with proper mgmt

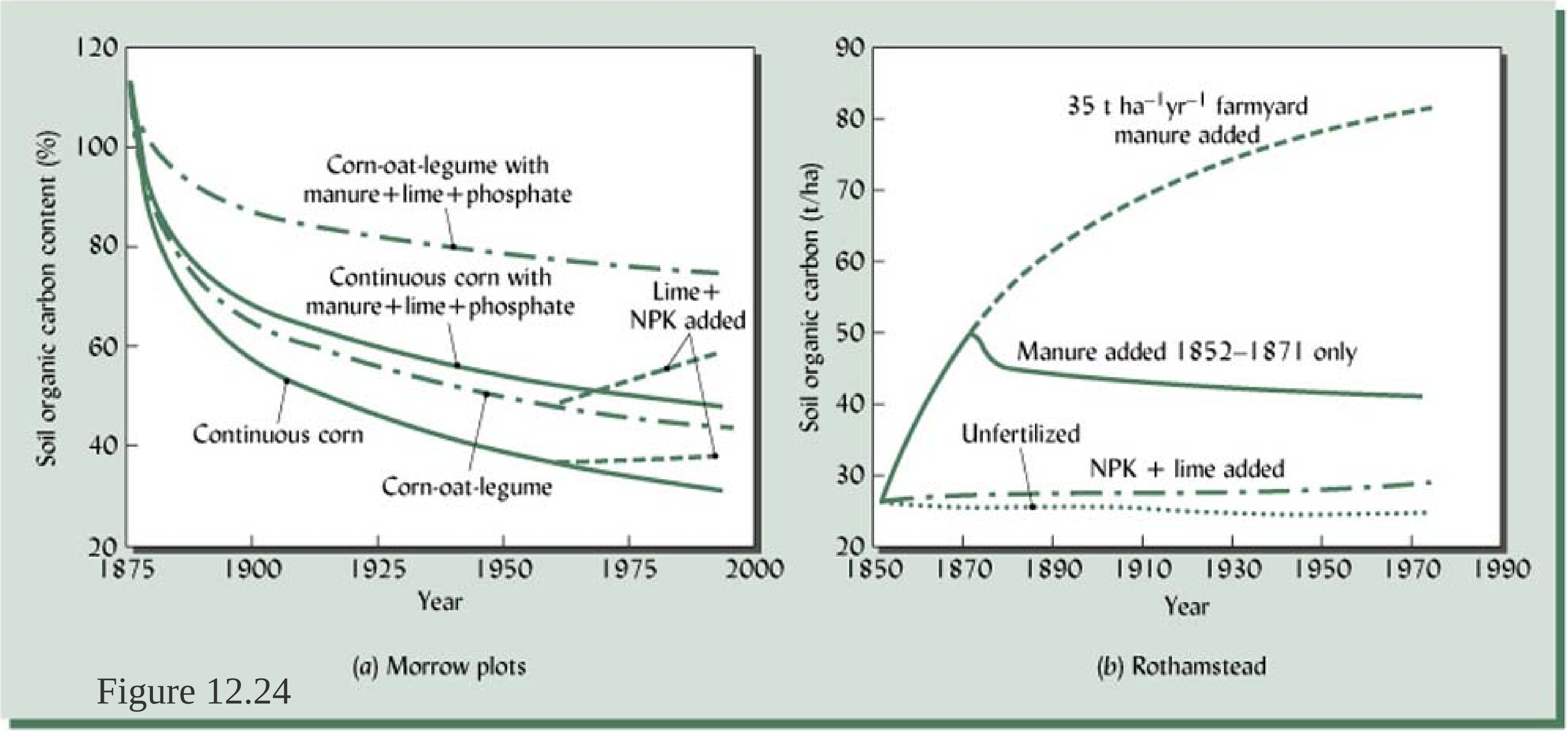


Figure 12.24

a) C-O-L higher OC; manure, lime, P helped maintain; lime increased
b) Barley, wheat no gain (equilibrium); NPK + Lime does not add like manure; manure for 20 years can still be seen 100 years later

Less tillage more SOM especially on surface

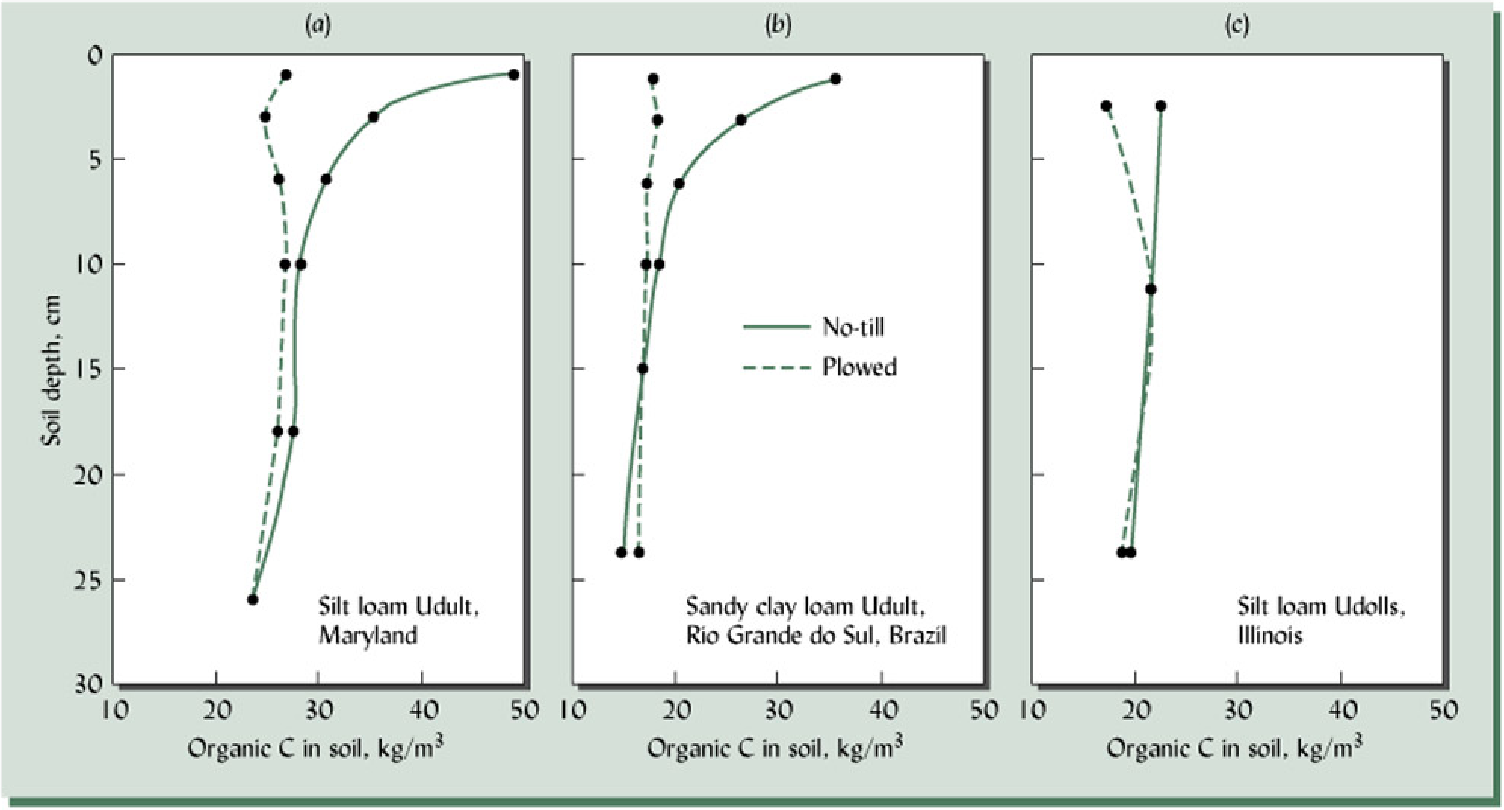


Figure 12.25

SOM is a flow- additions increase, oxidation decreases

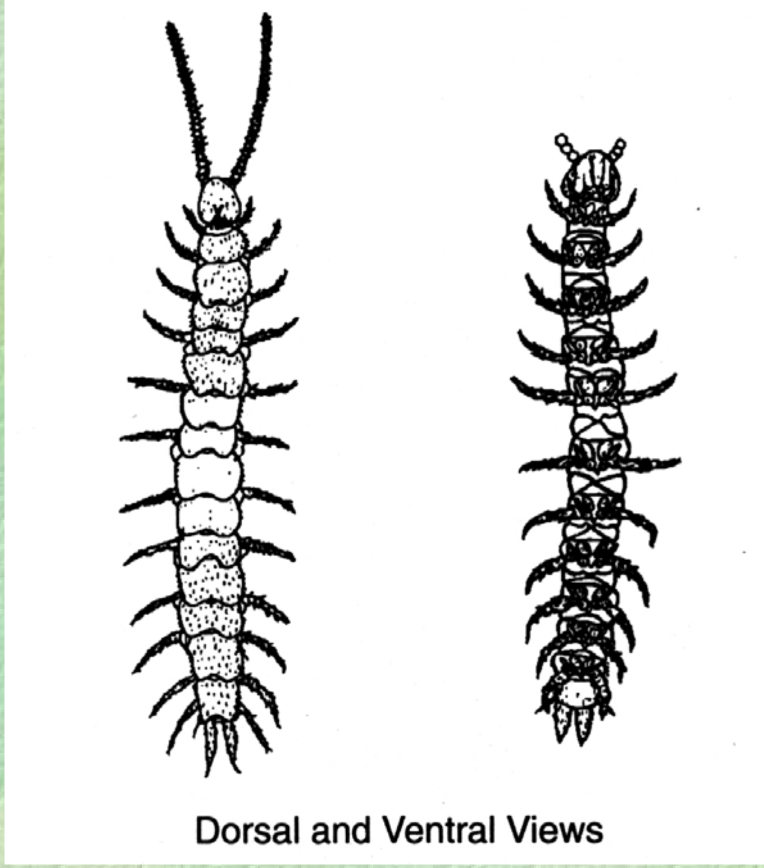
TABLE 12.5 Factors Affecting the Balance between Gains and Losses of Organic Matter in Soils

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

Recommendations for managing SOM

1) continuous supply OM needed to maintain, esp. active fraction
2) Not practical to maintain higher than native SOM
3) Adequate N needed for adequate SOM
4) High plant growth provides high OM, may need lime and nutrients
5) Reduce tillage
6) Encourage perennial vegetation

Can you have too much organic matter?



Symphylans

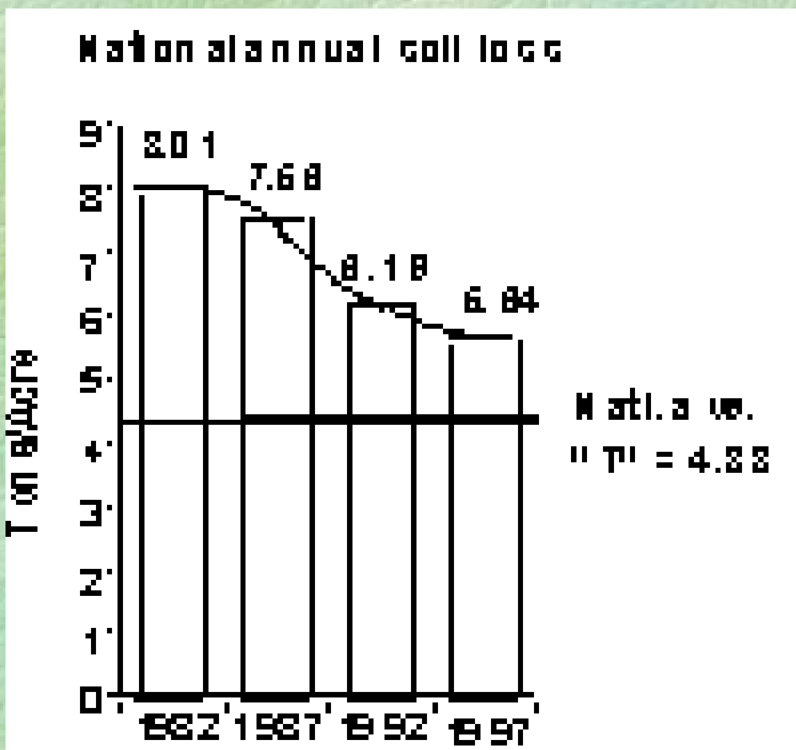
- Symphylans (not insects) are serious pest in high organic matter soils in PNW
- Fed by organic matter
- 10/shovelful is economic threshold
- Prune roots of brassicas, bean, celery, others

Histosols (peat and muck soils)

20-30% OM, mined for potting mixes

Figure 12.31. Peat mining for fuel in NW Scotland

NRCS, formerly Soil Conservation Service, is concerned with decreasing annual erosional soil loss in US

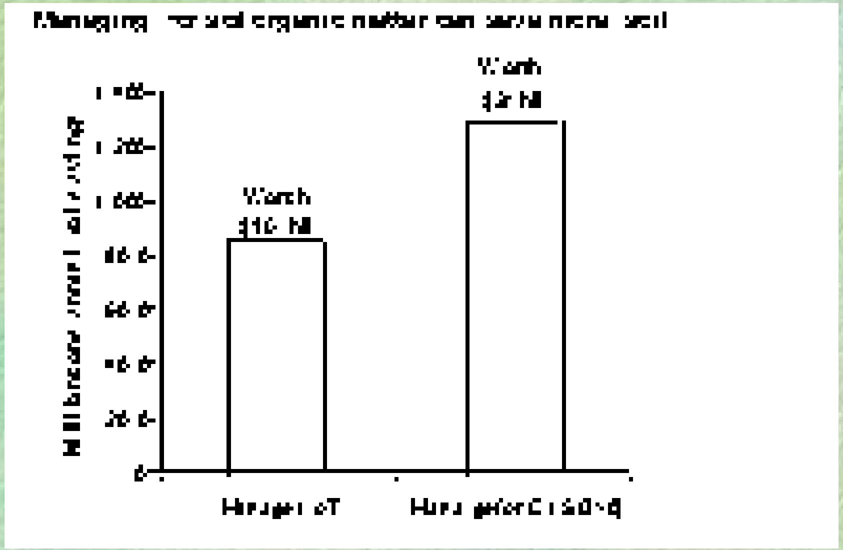


- Average soil loss is decreasing from 1982-1997

Soil Conditioning Index

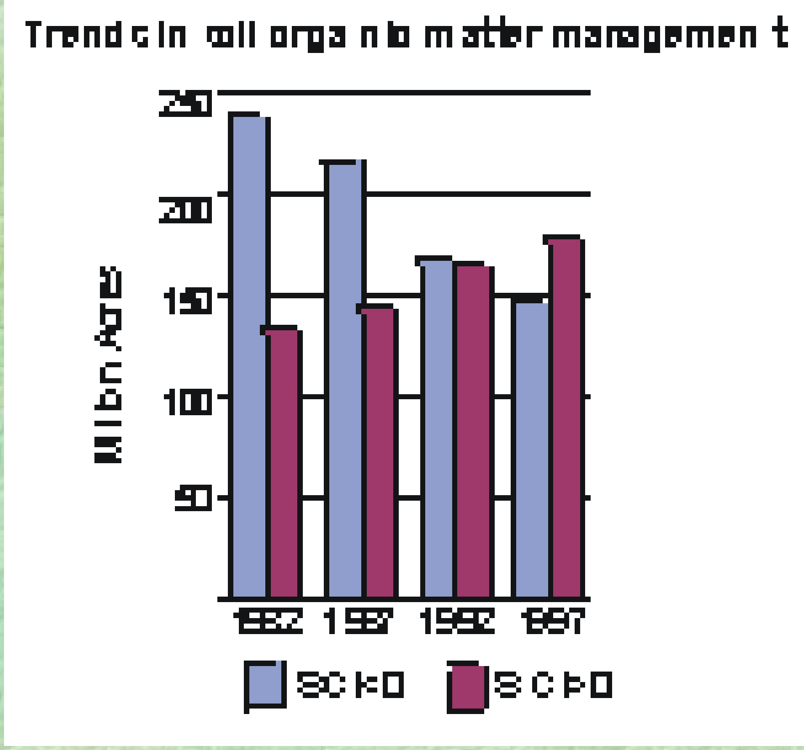
- Based on: organic material added (OM); field operation (machine passes, FO); erosion factor (EF) and other such as soil texture, decomposition rate due to climate, residue quality and C/N ratio.
- Farmer provides: location, soil texture, all crops in the rotation, typical yield; applications of organic material, field operations, rate of water and wind erosion

Budgets and Soil Condition Index-models to determine >SOM



- If manage to increase Soil Condition then annual soil loss savings would be $24.7 vs. $16.5 when managed to “tolerable soil loss” of 4.33 T/acre
- 1T/ac is soil replacement rate
- SCI can tell if increasing or decreasing in SOM.

Trends in US SOM management 1982-1997

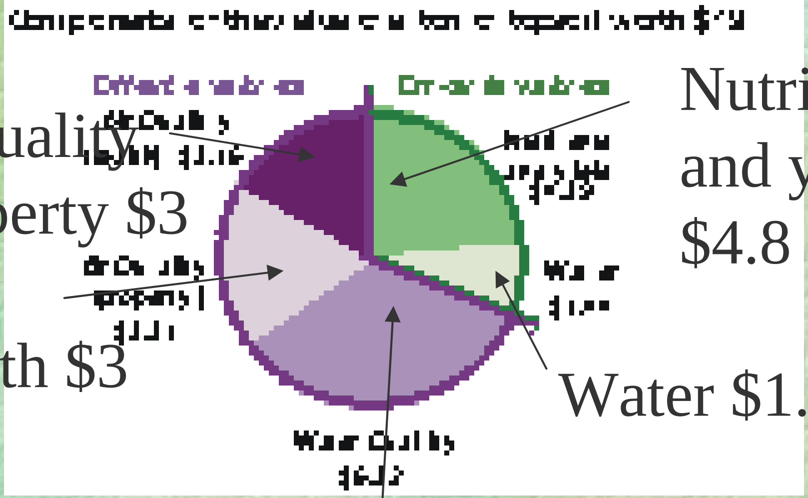


- Blue SOC < 1
- Purple SOC > 1

- Farmers are adopting management techniques that are increasing SOM

Ecol. Econ.: What is topsoil worth?

Purple: off site values ($1997)
Green: on-site values



Air quality property $3 and health $3

Nutrients and yield $4.8

Water $1.5

Water quality $6.6

Total $19/T

SOM cost effective in preventing erosion

Additionally:

- Cost of erosion to downstream navigation $0-5
- Cost to human health $3

Study Questions

- BW CH 12 #1, 2, 3, 4, 6, 8, 9.

Figure 12.29

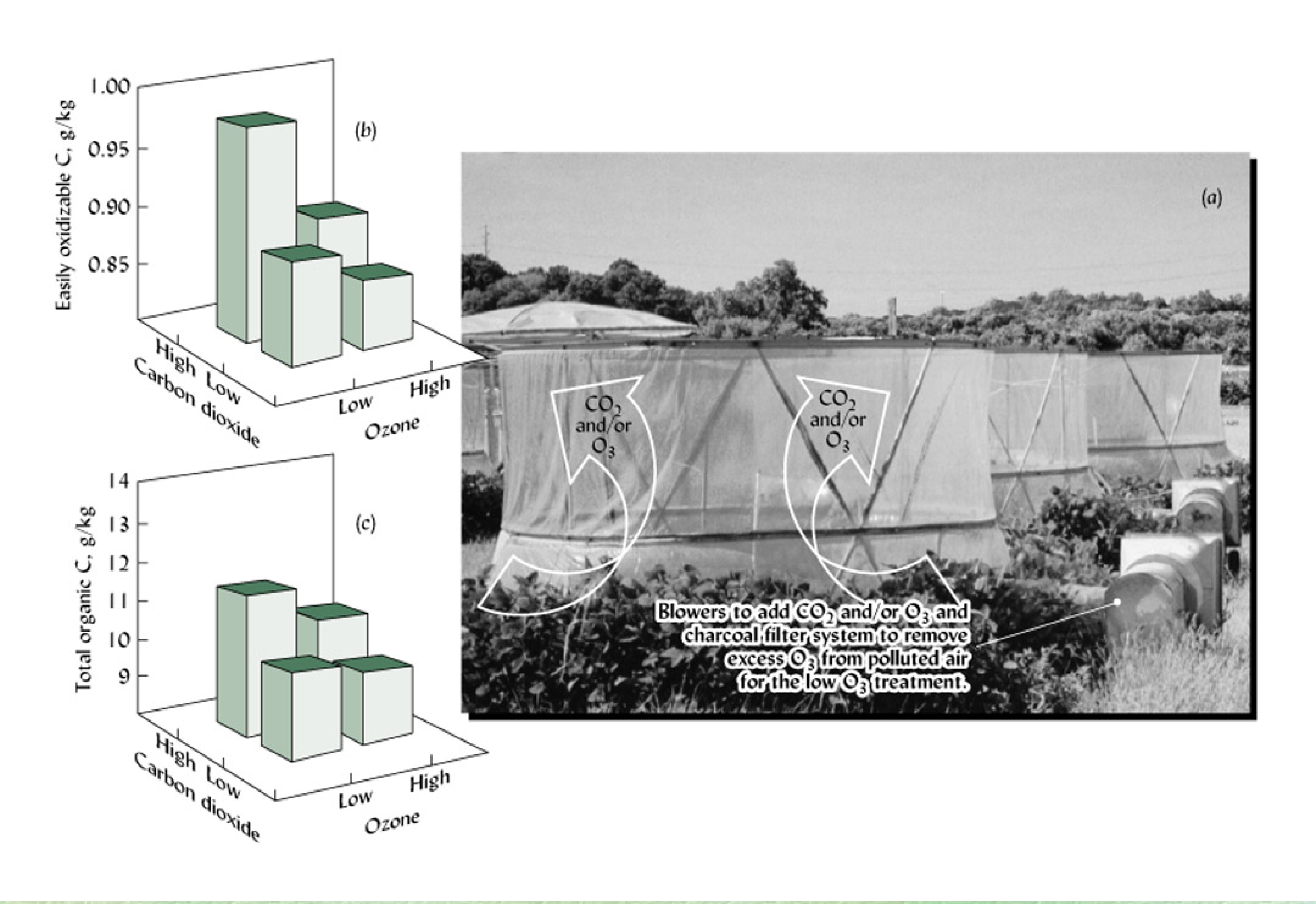

(b)
Easily oxidizable C, g/kg
1.00
0.95
0.90
0.85
High
Low
Carbon dioxide
Low
High
Ozone
(c)
Total organic C, g/kg
14
13
12
11
10
9
High
Low
Carbon dioxide
Low
High
Ozone
(a)
CO2 and/or O3
CO2 and/or O3
Blowers to add CO2 and/or O3 and charcoal filter system to remove excess O3 from polluted air for the low O3 treatment.

Figure 12.14

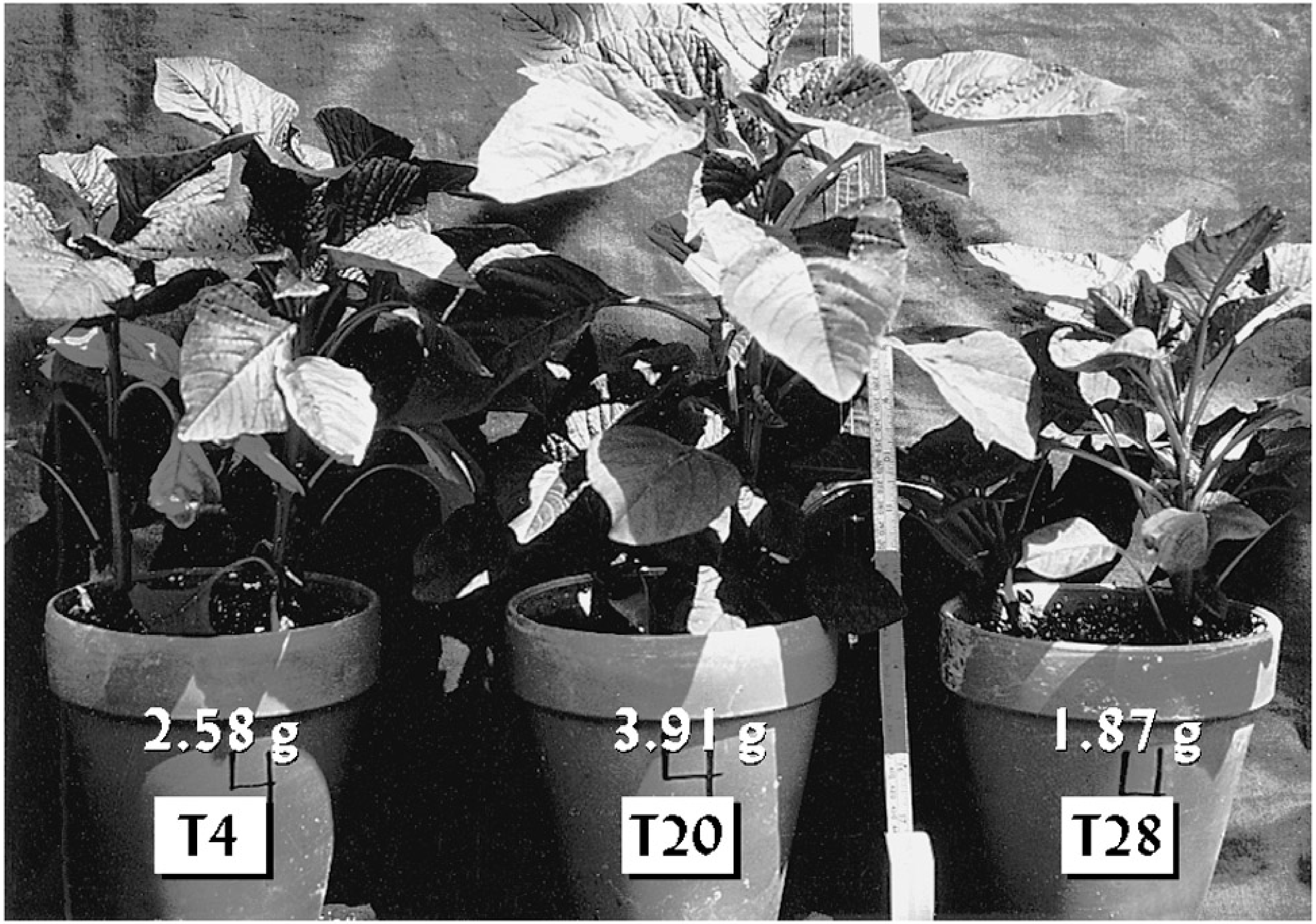


TABLE 12.6 Effect of Nitrogen Fertility Management Systems on Methane Oxidation by an Arable Soil (Mollisol) in Germany

The four nitrogen treatments were applied annually for 92 years to a rotation of sugar beets, spring barley, potatoes, and winter wheat. The measurements were made on soil sampled in spring, just before the annual nitrogen applications were made. Note that farmyard manure increased methane oxidation, while inorganic nitrogen fertilizer (NH_4NO_3) reduced methane oxidation from the levels in the control and the manure-only treatment.

Soil treatment	*Soil pH*	*Soil NO_3^--N, kg/ha*	*Soil NH_4^+-N, kg/ha*	*Methane oxidation rate, nL CH_4 L^{-1}/hr^{-1}*
1. Control—no N added in any form	6.8	0.83	0.20	4.60
2. Fertilizer N—40 to 130 kg/ha N as NH_4NO_3 to meet crop needs	6.9	15.36	3.1	1.34
3. Farmyard manure applied at 20 Mg/ha	7.0	1.98	0.22	11.2
4. Farmyard manure plus N fertilizer as in #3.	7.2	5.01	0.71	3.76

Data from the Static Fertilization Experiment begun in 1902 at Bad Lauchstädt, Germany and reported in Willison, et al. (1996).