Hello and welcome to the VCE Soil Webinar Series on 5-29-15. My name is Dr. John M. Galbraith. Today we will discuss soil organic matter.

Housekeeping

- This webinar explains soil organic matter and soil carbon types and content, and its response to management.
- The presenter is Dr. John Galbraith, a Soil Information Extension Specialist in Blacksburg.

This webinar explains soil organic matter and soil carbon types and content, and its response to management.

Structure - Topics

- Organic matter and organic carbon
- OM decomposition
- OM pools
- Carbon balance
  - Natural controls on OM levels
  - Managing organic matter
- Relevance to climate change and soil health

This slide is the outline of topics.

Learning Objectives

After viewing this webinar, the viewer will be able to:

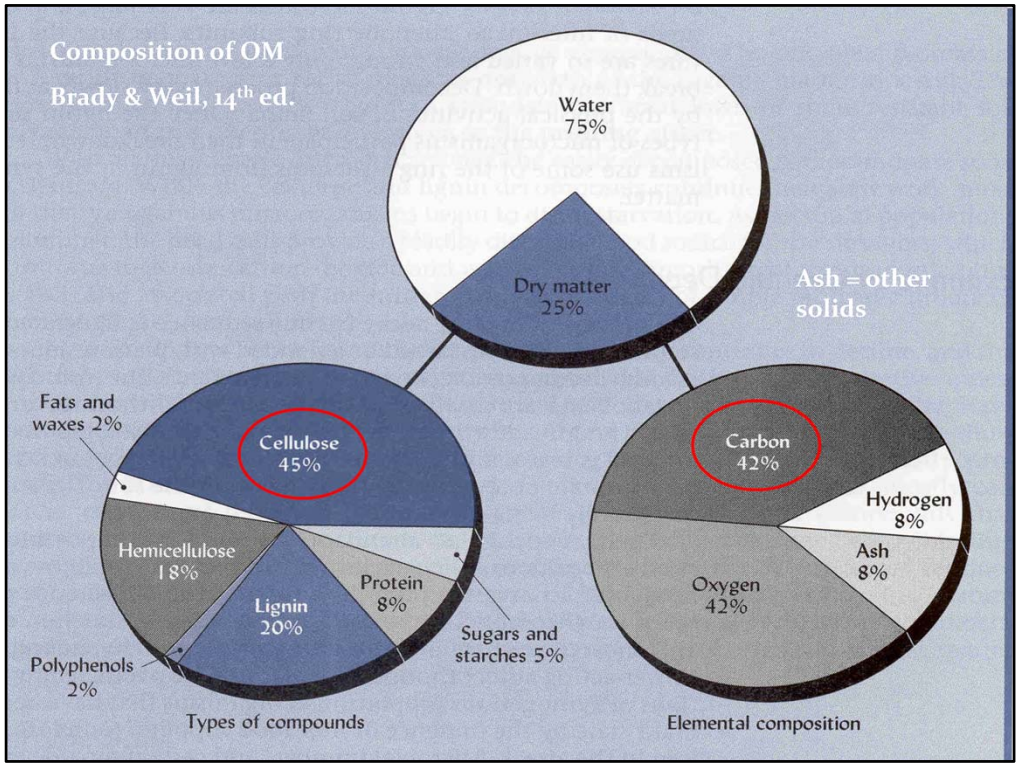
1. Explain the difference between organic matter and organic carbon
2. Explain organic matter decomposition
3. Know the difference in organic matter pools and relate that to decomposition and sequestration
4. Relate natural and management variables to the carbon balance in soils
5. Relate soil organic carbon content to soil management, climate change and soil health

These are the learning objectives of this webinar.

Background

- Soil Organic Matter (OM) occurs in various states of decomposition. When stable in the soil, called humus.
- Only a portion of OM is organic carbon (OC), but the two values are closely related.
- Almost all soils contain inorganic carbon (IC) as $CaCO_3$. Exceptions are soils in very humid regions or excessively leached soils.
- Total C = OC + IC

This slide explains the difference between organic matter, organic carbon, inorganic carbon, and total carbon.



Only about 25% of organic matter is solid. Of the solids, cellulose is the most common compound. Only about 42% of OM is carbon. 8% is ash (other elements), so about half of the OM is made of nutrients.

Origin of Soil Organic Matter

May be called litter/residue/manure/tissue but includes:

1. Dead roots and other plant tissue
2. Dead fauna bodies and faunal excretions
3. Exudates and leachates from living biomass
4. Microbes

1. Organic matter (materials) may be called litter/residue/manure/tissue, but included with soil OM are: Dead roots and other plant tissue, Dead fauna bodies and faunal excretions, Exudates and leachates from living biomass, and Microbes

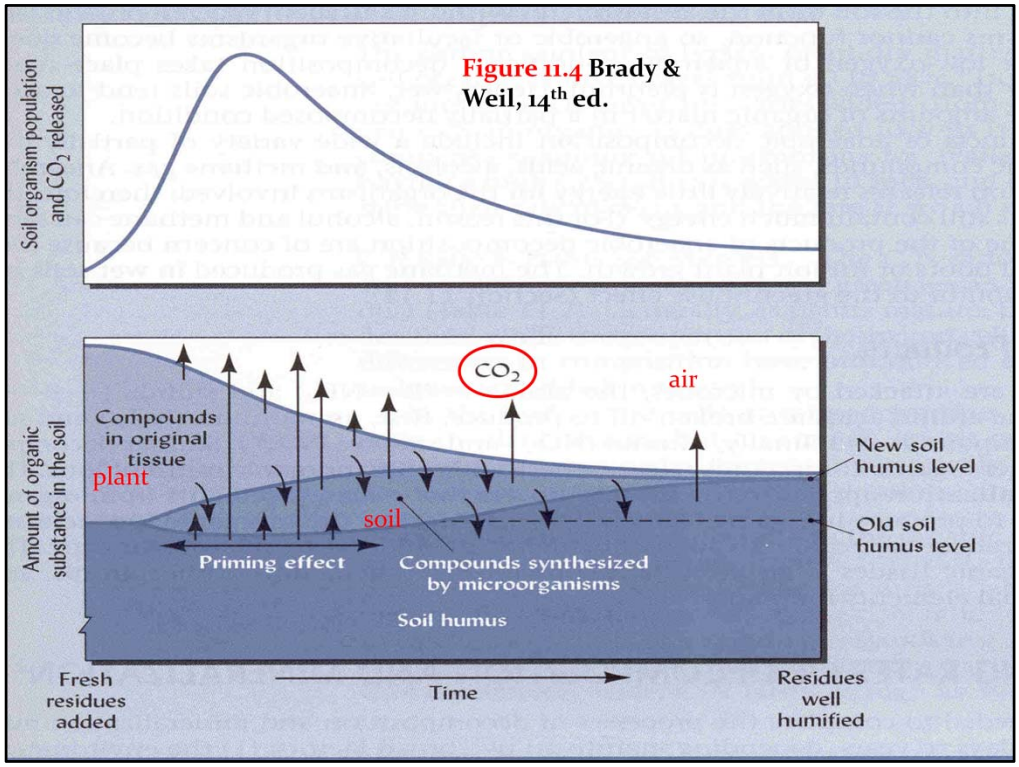
Factors Affecting Decomposition and Mineralization Rates

In general:

The time needed to complete the processes of decomposition and mineralization of SOM sources may range from days to years, depending mainly on two broad factors:

- The environmental conditions in the soil
- The quality of the added organic material

Decomposition (breakdown) and mineralization (conversion to inorganic nutrients) may take years, depending on the environmental conditions and the quality of the OM.



This figure shows an annual cycle, with fresh residue addition at the start, followed by a rapid rise in microbial activity and CO2 evolution. The microbes at the peak activity may be short on soil N so borrow some from the soil (priming effect) but as the original OM is broken down, it first moves into a pool of easily digested compounds and microbial mass and the remaining moves into the more resistant soil humus pool over time.

Specific Factors Affecting Decomposition and Mineralization Rates

- **Physical location:** tissue on the soil or in it.
- **Attachment** to clay or Fe or Ca or Al limits decomposition. **Clay coatings** protect OM.
- **Particle Size**: smaller particles are more rapidly shredded and decomposed.
- **Digestibility:** see chart
- **C/N Ratio**: very high C/N ratio residues will be limited in decay rate by available N.
- **P** is also required by microbes for energy and cell wall components, so low P in the soil may limit microbial populations.

Decomposition and mineralization take place in the soil, so the location of the OM is important. Clay is charged and attaches to the charged compounds, stabilizing it. Some clay may coat the humus, and protect it from microbes. As particle size decreases, decomposition increases. Different component compounds of the OM and also biochar have variable digestibility to microbes. The C:N ratio controls decomposition if too high or low, and some phosphorus is needed for decomposition to proceed.

Decomposition of Plant Organics

The rate of decomposition or "**digestibility**" of a given organic compound depends largely on what it's made of. Brady & Weil, 14th ed.

RATE OF DECOMPOSITION. Organic compounds may be listed in terms of ease of decomposition as follows:

1. Sugars, starches, and simple proteins	Rapid decomposition
2. Crude proteins	↑
3. Hemicellulose	
4. Cellulose Most abundant fraction	
5. Fats, waxes, and so forth	↓
6. Lignins and phenolic compounds	Very slow decomposition (become humus)
7. Biochar	Extremely slow decomposition

The simpler compounds are most easily decomposed because they have weaker, single, less complex bonds. The compounds with ring structures in 6 and 7 that share bonds are hardest to break. Biochar is very complex in structure and has strong bonds.

OM Quality

- **C/N Ratio**: Usually, low C/N ratio (< 40:1) materials are higher in proteins and are more palatable (microbes = 5:1 to 10:1)
- **Polyphenolic** materials lower quality because they directly inhibit microbial decomposers and some shredders
- **Lignin** lowers quality because it is very resistant to microbial degradation, primarily broken down by fungi, and partially hydrophobic

High quality OM has C:N ratio of 5:1 to 40:1. Microbes are 5:1 to 10:1. Polyphenolic materials lower quality because they directly inhibit the lives of decomposers. Lignin lowers quality because it is very resistant to microbial degradation, primarily broken down by fungi, and partially hydrophobic.

Table 11.2
TYPICAL CARBON AND NITROGEN CONTENTS AND C/N RATIOS OF SOME ORGANIC MATERIALS

Organic material	% C	% N	C/N
Spruce sawdust	50	0.05	600
Newspaper	39	0.3	120
Wheat straw	38	0.5	80
Corn stover	40	0.7	57
Maple leaf litter	48	1.4	34
Rotted barnyard manure	41	2.1	20
Bluegrass from fertilized lawn	42	2.2	20
Broccoli residues	35	1.9	18
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
Fungi	50	5.0	10
Soil organic matter Management effects			
Average forest O horizons	50	1.3	45
Average forest A horizons	50	2.8	20
Mollisol Ap horizon	56	4.9	11
Average B horizon	46	5.1	9

Recall the ideal C:N of 5:1 to 40:1. Higher than that is N limited, lower is C limited. Biosolids (sludge) are already highly decomposed, and microbes tend to bring the C:N ratio closer to their body composition, because they are a major source of food for other microbes. OM in forest O and A horizons less proportional N than grassland soils and subsoils, so their carbon is at a stability level.

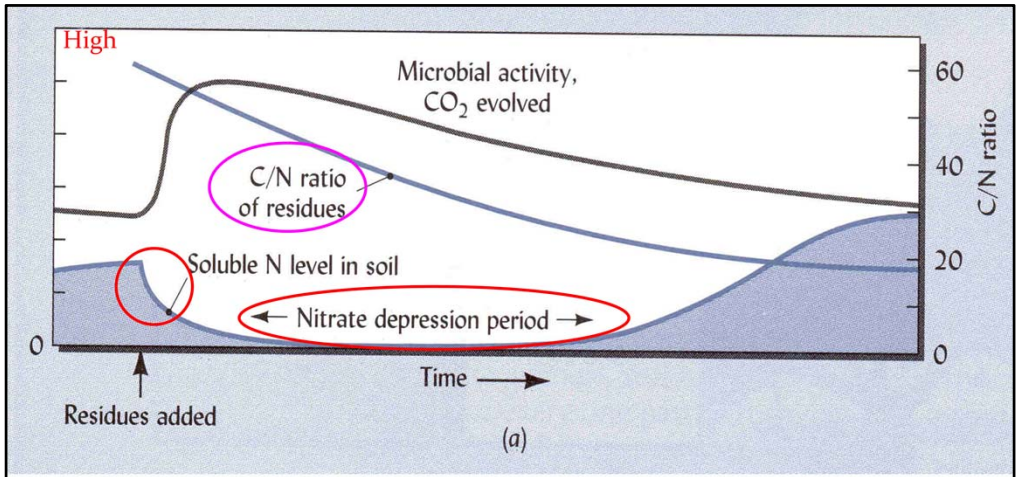


Figure 11.5a. Changes in microbial activity, C/N ratio of added residues, and nitrate levels in soils over time as freshly added, high-C residues are decomposed.

The C:N ratio of high-C OM starts very high and gradually decreases over an annual cycle, and there is a draw on the soluble N right after OM is added because of that. The C:N ratio is above 40. The nitrate builds later in the season as mineralization of OM occurs and microbial activity slows as C:N reaches about 20:1.

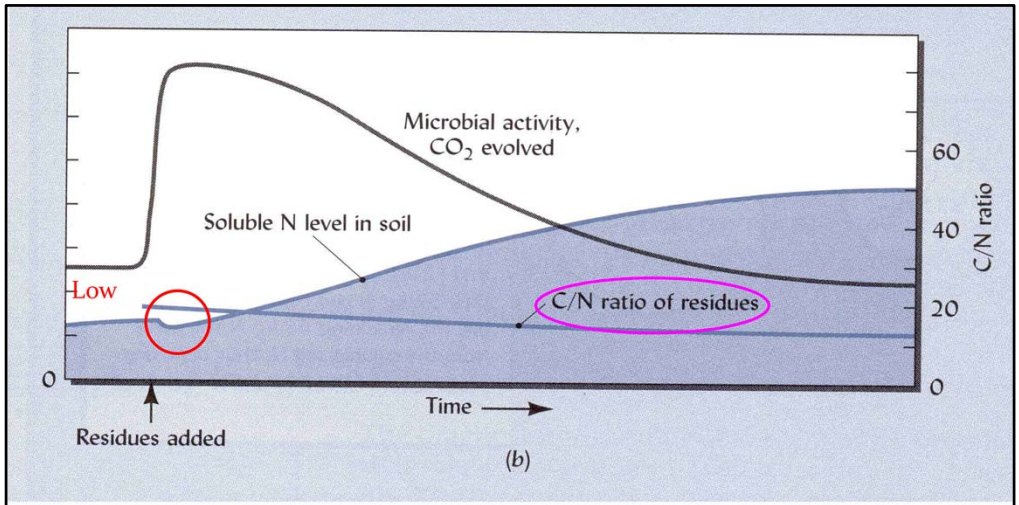


Figure 11.5b. Changes in microbial activity, C/N ratio of added residues, and nitrate levels in soils over time as freshly added, **low-C residues** are decomposed. Little/No nitrate depression.

The C:N ratio of low-C OM starts very low, and there is little draw on the soluble N right after OM is added because of that. The C:N is already in the suitable range. The nitrate builds throughout the season as mineralization of OM occurs and microbial activity slows, and the nitrate depression is so small it does not affect the plants. Low-C residue with lower C:N ratio is better for the plants, but may produce excess nitrate.

Quiz

- Which is a preferable addition to a field or pasture:

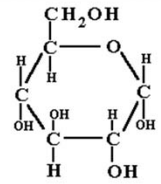
A. Low-C OM source

B. High-C OM source

The answer is A.

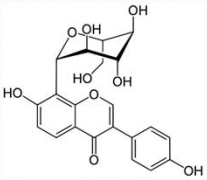
Humus - Two Constituents

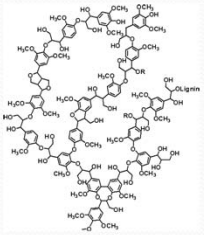
- **Non-humic substances** – ~30% of SOM; less resistant to microbial decomposition. Sugar, starch, proteins, hemicellulose, cellulose are major types.



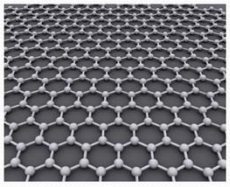
Glucose

- **Humic substances** – ~70% of SOM; stable, resistant to microbial decomposition. Polyphenols and lignins are major types.





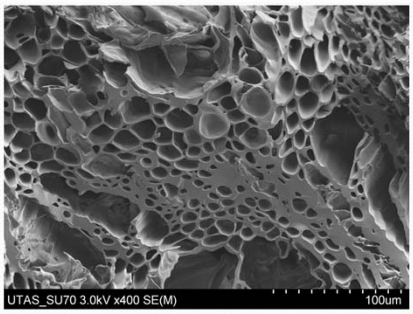
biochar



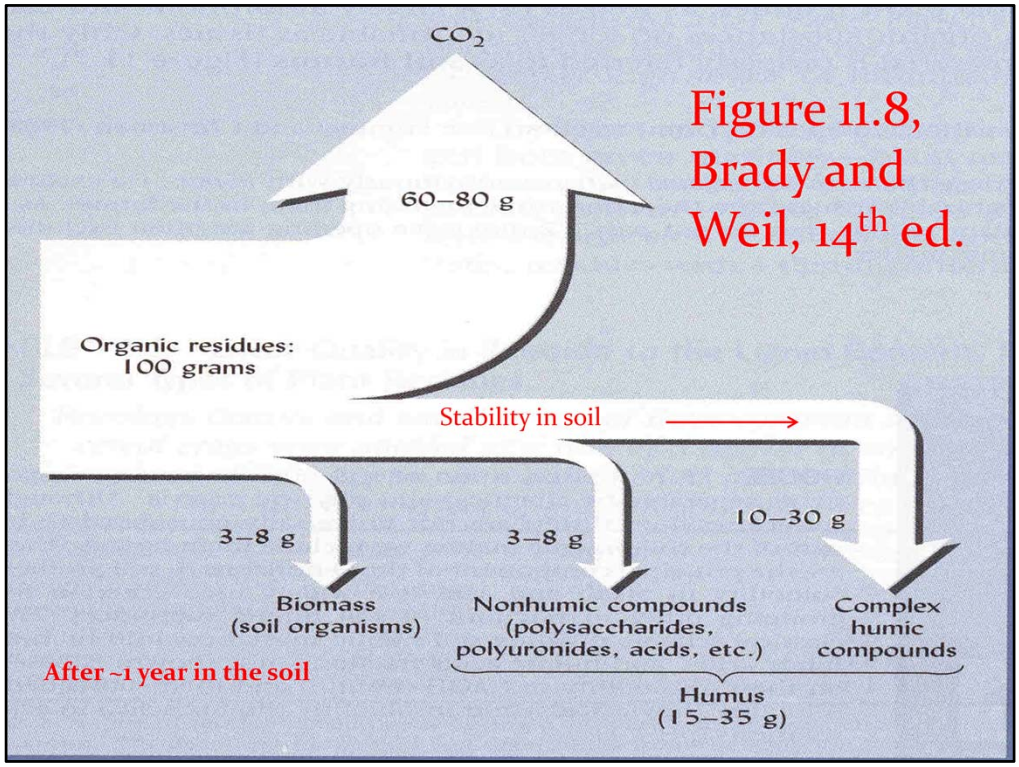
From the earlier chart, compound types 1-5 make up the non-humic materials. Glucose has simple bonds. Compounds 6 and 7 make up the humic substances and most ends up in the humus fraction of the soil. Polyphenols and lignin have shared, double bonds, harder to break. Biochar has strong C-C bonds.

Biochar - a Humic Substance

- Biochar – made of graphene, resistant to decay
- Has many soil and plant benefits, but caution – not all biochar is alike – many types, variable properties
- Retains original biological structures



Biochar is mostly carbon, and retains the structure of the original material. It has very high surface area and is resistant to decay.



60-80% of the carbon in OM ends up in the atmosphere, about 5% in biomass, and the rest as stable humus. Humic substances are 3-4 times as abundant in the humus.

SOM Pools

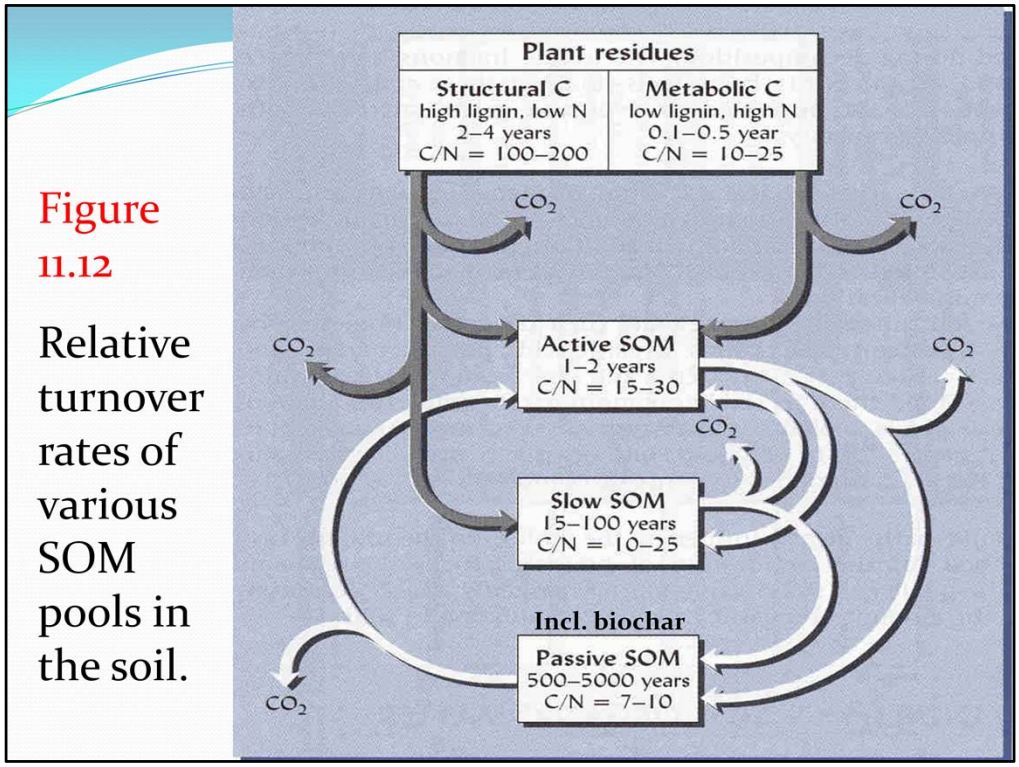
Plant and animal residue decompose into:

- Active pool - Easily and rapidly decomposed non-humic substances. **10-20%** of total SOM
- Slow pool –Mainly lignin and humic substances. **10-20%** of total SOM
- Passive pool - Mostly clay-humus complexes and colloids. Includes biochar. **60-80%** of total SOM

Active pool - Easily and rapidly decomposed non-humic substances.

Slow pool –Mainly lignin and humic substances.

Passive pool - Mostly clay-humus complexes and colloids. Includes biochar.



The turnover rate (how long it takes OM to completely decompose) is 1-2 years in the active pool, 15-100 years in the slow pool, and 500-5000 years in the passive pool. Biochar and physically-protected OM and OC last the longest.

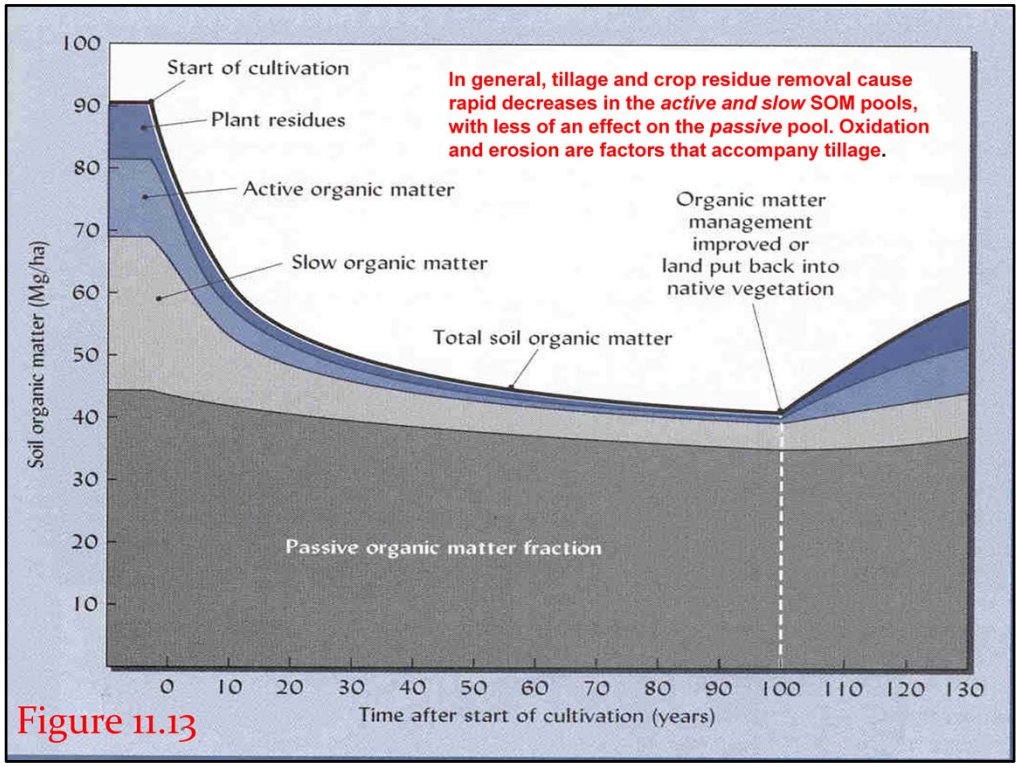


Figure 11.13

Over many years, it is the active and slow pools that are most susceptible to breakdown associated with plowing (oxidation, erosion, and aggregate breaking increases). Conservation practices can raise levels somewhat but not to former equilibrium levels.

Carbon Balance

- Rate of SOM increase or decrease depends on the balance between gains and losses.
- Gains:

  Plant residues and other OM additions (manures, sludge, biosolids, compost, etc.)
- Losses:

  Respiration (CO_2 loss), plant uptake, plant removal, erosion, DOC losses

Rate of SOM increase or decrease depends on the balance between gains and losses. Gains: Plant residues and other OM additions (manures, sludge, biosolids, compost, etc.) Losses: Respiration (CO_2 loss), plant uptake, plant removal, erosion, DOC losses

Natural Controls on OM Levels

Natural vegetation type:

- **Grassland soils:** Deeper, thicker A horizons – more carbon, biochar
  - Darker dominant organic acids (humic)
  - Biocycling of Ca stabilizes OM
- **Forest soils:** Distinct litter layers (Os) over As
  - Lighter colored acids (fulvic)
  - Little biocycling of Ca

Grasslands have darker soils, more humic acids, and higher OC content than forests. Grasslands also have more biochar.

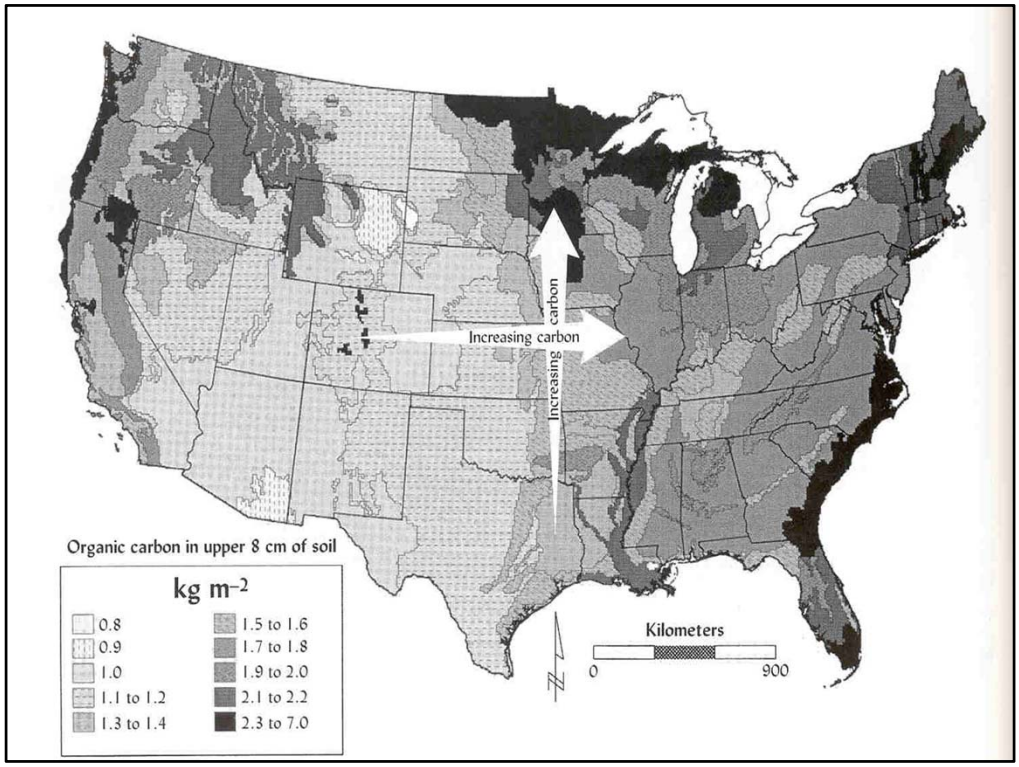
Natural Controls on OM Levels

Climate, Texture, Drainage, Management control losses:

- **Wetland soils:** Saturation and anaerobic conditions – higher OM, lower decomposition (unless drained)

- Climate = Temperature & Moisture
  - Moist, cool climates generate more OM inputs and limits microbial decomposition, leading to higher OM

Wetter soils have higher carbon content because of lower decomposition. Cooler temperatures also decrease OM decomposition.



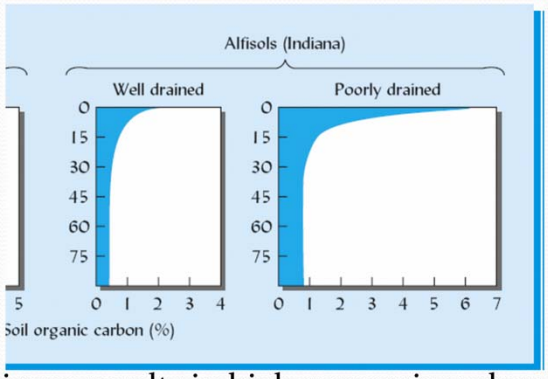
The combined effect of higher moisture and lower temperature.

Natural Controls on OM Levels

- **Texture**: Sandy soils allow ready losses of CO_2 and have few exchange sites to adsorb humus compounds, while clayey soils have lower CO_2 losses and retain OM via humus-clay associations. So, SOM increases as clay content increases!
- **Drainage**: Poorly drained wet soils retain SOM due the slower, less efficient nature of anaerobic decomposition.

Sands are not charged, cannot hold onto humus. They have less aggregation also. Sandy soils are lighter in color except in wetlands!

Figure 11.17 Distribution of Organic Carbon in Well and Poorly Drained Soils



Poor drainage results in higher organic carbon content, particularly in the surface horizon. The soil on the right represents a wetland soil.

Compare the OC distributions. Wetland soils have more carbon at all depths.

Managing Organic Matter

- Maintain a continuous supply of fresh, high quality inputs; keep the insects and microbes happy!
- Rotate crops, use cover crops to increase microbe diversity, reduce pests, diseases, and parasites
- Manage the crop residues to prevent erosion
- OM mineralization releases CO_2, NO_3^- (possibly up to 70 lbs. N per year), and some P and K and micronutrients

Maintain a continuous supply of fresh, high quality inputs; keep the insects and microbes happy!
Rotate crops, use cover crops to increase microbe diversity, reduce pests, diseases, and parasites
Manage the crop residues to prevent erosion
OM mineralization releases CO_2, NO_3^- (possibly up to 70 lbs. N per year), and some P and K and micronutrients

Managing Organic Matter

- You can only maintain a certain level of OM in any soil based on climate, drainage, texture, etc.
  - Most soils in Virginia have 2-10% OM, with the higher end in wetter soils.
  - Raising the OM content by 2% is an amazing accomplishment.
  - You can waste a lot of energy and money trying to "force" OM levels too high above their equilibrium point!
  - But wise management can minimize losses.

Most mineral soils in VA have less than 7% OM (5% OC). Be realistic. A 1% OC (2% OM) increase is all that can be sustained except by adding very resistant materials like biochar. But wise management can minimize OM losses.

Managing Organic Matter

- Adequate N must be available in soils to sequester significant amounts of C, because without N, CO_2 losses dominate (plants and microbes respire, but microbes can't break down much additional OM).
- Plant uptake and complete residue removal decrease SOM levels, esp. when annuals (crops) are grown rather than perennials and the litter is not recycled.

Inadequate N and complete residue removal will deplete the soil of OC. In developing countries, that is the current practice because of socioeconomics.

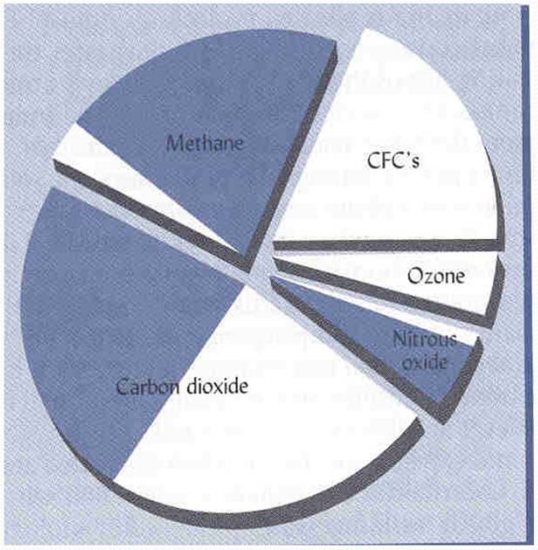
Soils and Climate Change

- Biofuel growth, processing, and combustion
  - Unclear whether there is a net increase or removal of CO_2 and CH_4
- Draining/filling Wetlands
  - Unclear whether the high sequestration rate and storage of C offsets the natural emissions of CO_2 and CH_4
  - Wetlands also release N_2O

The jury is still out on whether biofuel production and burning saves any C, and whether increased C storage in wetlands offsets their emissions.

Soil impacts on various greenhouse gases are shown in darker blue shades.

1. Soil efflux of CO_2 is about half of the global emission, but makes up the dominant component of CH_4 and N_2O.
2. Soil efflux of all three makes up about half of the global output!



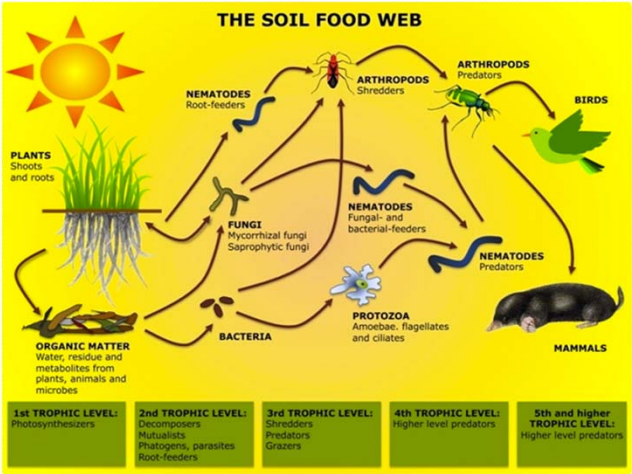
Soils are the source of about half of the greenhouse gas emissions on earth.

Soil Health

- Higher OM means a steady supply of nutrients through mineralization
- Higher OM means lower bulk density, greater porosity, less compaction
- Higher OM means higher water holding capacity
- Higher OM/OC means better aggregate stability, less erosion and crusting
- Higher OM means more food for microbes
- Higher OM relates to better biodiversity of microbes, plants, and animals
- Humus improves chemical properties:
  - Cation-exchange capacity
  - Soil mineral weathering release (through chelation)
  - Lower Aluminum toxicity (buffers pH and attaches to free Al)

List of all of the benefits of OM and humus to soil health.

Biodiversity Through Soils



High biodiversity improves soil health for all life. Checks and balances between good and bad organisms.

Carbon Sequestration in Soils

- There is great current political and governmental interest in building soil C pools via reforestation, minimum tillage, and other practices. Be realistic!
- If documented, credit for soil C sequestration may be used to offset excess C emissions from other sources.
- "C credits" may be traded nationally and internationally once a regulatory structure and market is established.
- Placing economic value on storing OC in soil should benefit the environment - offering an economic incentive to preserve carbon-sequestering wetlands, avoid excess emissions, or take proactive sequestration "offset" measures.
- But how to greatly increase the amount stored in the soil??? Increase aggregate stability, add biochar.

Carbon credits are explained.

Questions?

- Webinar and training requests https://survey.vt.edu/survey/entry.jsp?id=1418409961833
- Check in on soils Information
  - Twitter @VAsoilguy
  - Facebook www.facebook.com/IheartVAsoil/
  - VCE web page http://www.ext.vt.edu/

Virginia Cooperative Extension
Virginia Tech • Virginia State University
www.ext.vt.edu