Soil: Not Just Dirt!

Darien Payne, Master Gardener, on Soil, Growing Groceries November 14, 2018

My goals for this talk: that all of you leave with a new or renewed respect for the life underfoot, and that you begin to nurture your soil as if it really matters.

1. Welcome to Growing Groceries class #2: Soil and Compost

2. Short outline of part I, Soil

I. What is soil? How is it formed? Puget Sound Soils in particular

3. Big Picture: Soil is the meeting and mixing of Hydrosphere, Lithosphere, Atmosphere, Biosphere. The fount of terrestrial life.

4. Factors in soil formation: Parent material—original rock (mineral nutrient bank) Puget Sound soils formed by glaciers, primarily glacial till and outwash, some volcanic mudflows (Enumclaw plateau).

Climate—Our climate—wet, cool temperate. Rain cools the soil, leaches calcium and other minerals, contributes hydrogen thereby lowering pH.
Topography—*sloped or flat, aspect* Gravity influences erosion, deposition of minerals moved by water and wind. Low spots are Alluvial soil, with more sediment deposited above the glacial till, lacustrine or . Slope and aspect create microclimate differences: south facing slopes and terraces will be warmer than north facing. Our regions varied terrain provides us with a variety of soils.
Time—takes eons to build soil. Puget Sound soils are relatively young, created after last glacier retreat about 15,000 years ago.
Living Organisms—The early living organisms "weathering" rock: lichens, partnership between photosynthesizing algae and rock mining fungi. Plants and soil organisms add organic matter, gluing together soil particles, cycling nutrients, mixing soil layers. Lichens are an example of biological "weathering" which creates soil. Other life such as grass, ants, earthworms, trees, etc. (and including humans) have an impact on the soil. **Weathering** is the word used to describe the process of turning rock into soil. But all weathering is not weather... Life contributes a lot of the "weathering" of rock into soil. The fungal partner of lichens etches minerals from rock in exchange for carbohydrates from the algal partner.

5. Three Components of Soil: or, three ways of looking at soil
Healthy soil is created when the three components of chemical, physical, and biology are in balance.
Characteristics of healthy soil:
Good soil tilth or **structure**
Sufficient depth
Good water storage and good drainage
Sufficient supply, but not excess of nutrients
Small population of plant pathogens and insect pests
Large population of beneficial organisms
Low weed pressure
Free of chemicals and toxins that may harm the crop

Resistant to degradation
Resilience when unfavorable conditions occur

6. Physical: Texture—Soil texture is mostly influenced by parent material and geological history. Our glacial till soils are composed of lots of silt and gravel, and larger rocks. Lower horizons have higher proportion of clay. Glacial lake beds, lacustrine soils, have more sand and less gravel. Puget Sound's varied terrain and many microclimates have given us a variety of soil textures.
Soil texture: *we get what we get*. Difficult to change soil texture by adding clay or sand, you could end up with concrete.

7. Physical: Soil Horizons: the way time, topography, and gravity have arranged the soil layers. On the left a simplified illustration of horizons, or layers, and on the right a sample of Alderwood series from Puget Sound region. Young soil, no E horizon. Did you know the soil in your garden has a name?

8. Chemical: Nutrient stores and flows. Keywords: **Soil solution, cation, anion, adsorb**. Mineral nutrients (mineral elements and compounds) are **adsorbed** or held onto the surface of soil particles by weak electron bonds. This is a dynamic system, as the minerals are loosely attached to the soil particle surface, with others clustering close by, ready to jostle the adsorbed minerals to replace them on the surface. The mineral nutrients are called **ions**, molecular compounds of water soluble minerals. Positively charged minerals are **CATIONS**, and negatively charged minerals are **ANIONS.** Most of the plant essential minerals are positively charged cations. Clays and humus have many negatively charged attachment sites that attract the cations, and fewer positively charged sites to attract anions. Think of these soil particles as a bank account from which the plants can withdraw nutrients. Sand and silt particles have many fewer attachment sites. **Humus** particles have many more attachment sites than most clays.

It isn't exactly like a battery. But it helps me to think of it similarly, as a dynamic mixing, moving mineral stew. (Baking soda and vinegar), mix, meet, attach, separate, move.

Plants can only take in nutrients through the watery soil solution. Plant roots exude H ions, which knock the other minerals off the soil particle, so they are then in the soil solution and can be taken into the plant cells.

9. Chemical: Nutrient stores and flows. **pH** of soil determines which minerals are available to plants. Our soils tend to be acidic. Optimum range (for most landscape plants and mineral availability) is just slightly acidic, 6–7+. Lower numbers are more acidic, higher numbers more alkaline, 7 is neutral.

High rain tends to lower pH. Hydrogen displaces the other minerals which leach down slope or to lower soil horizons (layers). We are used to thinking about adding chemicals to our soil to improve them, but excess soluble minerals may be **leached**, or sent by rain and gravity, to the subsoil, below most plant roots' reach, or into the groundwater.

10. Biological: Keyword— Organic Matter. Research into soil biology is more recent, most done in the last few decades since the invention of the electron microscope. The pyramid represents the life in soil, from smaller organisms to larger. Bacteria, smallest, 10 trillion individuals in one square meter of natural forest or prairie soil. What is **Organic Matter? Living, dead, the very dead, CARBON.** Soil components by volume = approximately 45% mineral (sand, clay, silt), 50% pore space, for air/water, 1% to 5% organic matter. Some long used agricultural soils, conventionally farmed, have less than 1% organic matter. 2% is considered adequate for agriculture. Native midwest prairie soils can have 12% + organic matter. Peat bog soil can be much higher. Of that small percent organic matter, only 5% of it is currently living. 10% is fresh residues, or "recently" dead material, 33–50% "active fraction" or less recently dead, or excreted material that still provides food for soil creatures, and is cycling through organisms. 33–50% is in stable, long lasting organic matter, **humus** or humic substances. Healthy soils have a continual supply of fresh organic matter. **Humus** has been cycled through digestive tracts so long that nothing wants to eat it. Humus can be very long lasting, and is resistant to decay. Humus holds and releases nutrients: **Cation exchange**. Humus has much higher CEC than most clays.

Part II Plant–Soil Interactions

11. Photosynthesis: It starts with the sun! Keywords—photosynthesis, exudate, rhizosphere. Plants use energy from the sun to convert CO2 from the atmosphere into sugars, carbohydrates, cellulose, lignin. Cellulose and lignin are structural support for the plant. Carbon is fuel, for plant metabolism and the metabolism of the whole of the food chain. Plants use the sugars to store for energy, and surprisingly, can offer, or **exude** (leak, discharge), 10 to 40% of the sugars they create from carbon dioxide into the soil. These exudates are a donation to the life in the soil. Most of the soil life is concentrated around plant roots, the **rhizosphere** . That is where the sugar is! On the right a photograph of midwest native prairie plants. Look at those roots! Must be 8 feet long. Consider all the carbon/sugars those roots exuded into the soil, and all contained within the roots.

12. Carbon Cycle: Carbon even cycles through the Lithosphere. Limestone is a rock, calcium carbonate, created over eons from ancient marine life, corals and similar organisms. Fossil fuels are also a carbon reservoir from ancient life, a product of photosynthesis millions of years ago. The ability of plants to donate excess carbon to soil life, and the ability of the biological processes within the soil to gradually turn that carbon into **humus** , implies that plants and soil biota can **sequester** (remove from atmosphere & store) carbon to aid in mitigating excess Carbon from the atmosphere.

13. Nitrogen Cycle: Keywords—nitrify, immobilize, mineralize, denitrify. Nitrogen and carbon are two essential elements whose source is atmosphere. Most other plant nutrients come from the soil. Nitrogen is volatile, changes easily from one form to another. Plants do not use it directly from air, but **nitrifying** soil bacteria do. Some are symbiotic/mutualist organisms, trading N for sugar offered by plant exudates. There are also free living nitrifying soil bacteria. N is stored in soil organisms, **immobilized** until excreted as waste (**mineralized**) or until the organism dies and its tissues are available for other organisms. N is essential for photosynthesis, DNA synthesis, and amino acids (proteins). Excess soil N is "**denitrified**" or converted back to a gas, atmospheric form, by **denitrifying** bacteria.

Two soluble forms of nitrogen that plants use are ammonium and nitrate.

Excess N is easily leached from soil and is a toxic pollutant of ground water. Excess N is also can enter the atmosphere as nitrous oxide, a potent greenhouse gas.

14. The Soil Food Web: Keywords—producers, consumers, biomass, biota The soil food web is the term for the food chain of the terrestrial ecosystem. Eat and be eaten. Photosynthesizing organisms—plants, algae, lichens, photosynthesizing bacteria—are the **producers. Consumer** is the ecological term for the rest of the life dependent on the producers for calories: from microbes to mammals. The weight of both the consumers and producers is the **biomass** of a system. The healthier and more diverse the **biota** (living organisms), the higher the **biomass.** A healthy, functioning soil food web, powered by the sun, continually cycles and also stores nutrients within the system. Consider a healthy salmon cycle: the salmon periodically return from the ocean to spawn, bringing marine nutrients to the upstream ecosystems. Those nutrients are mineralized by the salmon eaters, excreting excess nutrients into the soil for other organisms to use.

15. Bacteria, Actinomycetes, Nematodes and Protozoa: Upper left, small rod-shapes bacteria on a root hair or fungal hypha. **Rhizosphere!** Lower two, Nitrogen fixing mutualist bacteria on soy host plant. The nodules contain the N-fixing bacteria. Bacteria can be pathogens or mutualists. They concentrate in the rhizosphere. Bacteria produce glyco-protiens, bacterial slime, which helps glue soil particles together. Upper right photo is of actinomycetes, organisms genetically related to bacteria, but their shape is thread-like nets. They are often anti-biotic (streptomycin).

Nematodes can be either herbivores or predators. Nematodes are varied and eat a variety of organisms. Their mouth parts identify what they eat. Bacterial feeders have those elaborate mouth parts. Protozoa eat bacteria. Both are “secondary consumers.” These creatures offer “micro manures” as they cycle (mineralize) nutrients.

16. FUNGI: soil builders. **Key words: hyphae, arbuscular mycorrhizae, ectomycorrhizae, glomalin**

Three types of fungi: **pathogens** (disease causing), **saprophytes** (decomposers), and **mycorrhizal** (mutualist, beneficial to plants). Pathogenic fungi we want to reduce their populations in the soil. Saprophytic fungi are essential for decomposing woody and high lignin plant materials, cycling the nutrients. Mycorrhizal fungi we want to encourage for plant and soil health. Mycorrhizal fungi are important in plant uptake of phosphorus, they mine from rock and offer to plants. Soils with excess of phosphorus are detrimental to mycorrhizal fungi. Fungi also scavenge and share other nutrients with plants, including nitrogen. Most vegetable plants form symbiotic relationship with **arbuscular mycorrhizal fungi**. Exceptions are beet family and cabbage family, which do not form mycorrhizal partnerships. Mycorrhizal fungi not only exchange mineral nutrients for sugars from plant exudates, they also help protect the plant partner from pathogens and nematodes, by creating a protective shield of chitin around the root. AMF also create **GLOMALIN,** a glyco-protien (sugar-protein compound), in the rhizosphere. Glomalin stores carbon, nutrients, water in a gel like substance. Very slow to break down, can last 4 to 40+ years in soil. Provides plants with some moisture insurance, nutrient reservoir, protective sheath. Glomalin is glue to create **soil aggregates,** along with fungal hyphae. Glomalin was identified as a soil protein Sarah Wright in 1996. Lower right, a piece of feldspar rock with tunnels mined by fungal hyphae. Upper right, close up of the fungal hyphae, an **arbuscular mycorrhizal fungus**, with those thin hyphae. Those thread-like hyphae can reach into crevices and extend the reach of the plant root. Spheres are fungal spores (reproductive bodies).

FUNGI diagrams—Top Left **Endometrial arbuscular mycorrhizal fungus** send hyphae into the plant cells and exchange nutrients with the plant. Lower left: Ectomycorrhizal fungi colonize about 2000 plant species, mostly woody trees/shrubs, conifers, some perennials. They do not enter into the plant cell but go in between the cell membranes to exchange nutrients, and form a protective mantle around the root.

There several other similar mycorrhizal fungal families that forms partnerships with ericaceous plants, like blueberries, in acidic soil. Orchid family has another kind of mycorrhizal fungal partners.

Fungi and bacteria can be either pathogens or partners with plants.

17. Arthropods: protozoa, some nematodes are fungi & bacteria eaters; some are shredders/decomposers of dead plant material. Other arthropods & nematodes are predators of smaller organisms. Birds & animals eat them. All those small & smaller creatures provide **micro manures**! The living creatures of the soil convert the mineral nutrients into plant available forms.

18. Earthworms illustration by James Nardi. We all know earthworms are soil builders. They function as decomposers, shredders, nutrient cyclers, mineralizers. Their tunnels and burrows are nutrient rich (all those worm castings) and provide pore space for roots, air, water to enter the soil.

19. Soil Aggregates: Habitat, hot spots of biological activity. Lots of keywords here!

Rhizosphere the area within an inch of roots. Rich with carbon exudates from plant roots provides food for all soil fauna and fungi. Those carbon exudates encourage high populations of soil biota.

Detritusphere the area of recently dead plant and soil surface dwellers, the O horizon.

Drilosphere the area in and edges of earthworm burrows. Highly fertile space for roots, oxygen and water access, pathways for soil organisms.

Porosphere the realm of soil pores, both micro and macro. Air and water exchange, habitat for soil organisms, pockets of humus.

Aggregatusphere the area of soil aggregates, micro and macro. Roots, fungal hyphae, bacterial slime, create glues and threads that bind soil particles together, forming pockets of life and nutrients, and pore space for air & water. Absorb and release water.

Soil **structure** best if it is cottage-cheese like, clumping in small aggregates that then clump together in larger aggregates.

How are aggregates created? Roots, especially grasses, bacterial slimes, fungal hyphae, glomalin.

PART III Gardening for Soil Health

20. Soil Health: "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans" —Natural Resources Conservation Service

Principles for gardening for Healthy soil:

- ***Keep soil covered as much of year as possible.***
- ***Maximize living roots in the soil profile.***
- ***Minimize soil disturbance.***
- ***Energize the soil system with biodiversity.***

Characteristics of healthy soil:

Good soil tilth (structure)
Sufficient depth
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Resistant to degradation
Resilience when unfavorable conditions occur

21. Know What You Have: Keyword—CEC Cation Exchange Capacity Most useful numbers on a soil test might be pH, Soil Organic Matter percent, **CEC**. **CEC** is the ability of the soil to store nutrients on surface of soil particles. Higher CEC is better.

This particular soil test is very high in P, and very high in organic matter. This garden likely had excess manure applied, over a number of years. Too much P can leach into groundwater, cause algae blooms in ponds, lakes, which can then result in collapse of aquatic ecosystem.

22. Fertilizing Your Garden: Less is More! Synthetic fertilizers are very soluble, quick acting, therefore prone to leaching. They do not feed the soil life, and in fact can discourage plant mutualist organisms. Synthetic fertilizers require a lot of fossil fuel energy in their manufacture and transport. Synthetic N tends to increase soil acidity. Organic fertilizers are often a waste product from a plant or animal product. Organic fertilizers are generally slower acting, but also can be taken up into the soil nutrient bank by soil organisms, and provide a longer lasting source of nutrients. Observe your soil. Are there earthworms, soil aggregates? If you have some organic matter in your soil, it should be OK to add an inch of finished compost in the spring.

If it seems your soil is very low in organic matter, add up to three inches of compost.

Safe use of manure as Dr Cogger recommends:

- Incorporate compost well before planting
- Apply to rotation crops not harvested as food
- Use legumes instead
- Use processed, not raw, manures

•“Waiting periods” between application and harvest (90 or 120 days for National Organic Program) are general recommendations, not infallible truth.

•NEVER apply manure or manure-based teas to food crops nearing maturity or harvest

23 Benefits of Cover Crops: Cover Crops are crops planted primarily for the benefit of the soil life rather than as an edible or other crop for human use.
- Replace soil organic matter
- Recycle nutrients
- Supply nitrogen (legumes only)
- Protect soil from rain and wind erosion
- Reduce runoff and water erosion
- Reduce leaching of nutrients
- Suppress weeds
- Break up compacted soil
- Attract beneficial insects by providing pollen and nectar
- Reduce disease and nematodes

24. Fall and Winter Cover Crops capture excess nutrients after summer crops, protect soil from winter rains, and provide continued carbon (fuel) for soil organisms, building soil organic matter.

Natural Resources Conservation Service recommends planting at least five species and at least three plant families. Diversity is better! Diversity is insurance, if one or more species fails, there are others that will survive. Diversity above means diversity below ground, you will be feeding diverse species of soil biota. Brassicas do not form mycorrhizal relationships, but can have a bio-fumigant effect on the soil. Legumes fix N so are essential in bringing more N to your soil. Even winter crops grown for food are covering your soil and feeding soil life.

Best to plant them by mid September. Earlier plantings provide more biomass, but smaller younger plants can survive a severe frost more easily. Rye, Triticale, and fava beans can be planted the latest. They may not show much growth until spring, but they should survive winter and grow well in spring.

Mulch the cover crop seeds lightly so that birds cannot get them all. Make sure they are covered with soil too, to protect from mice and voles. August and early September plantings will require some irrigation.

Over seed to compete with weeds.

You can interplant even earlier, in July, between young corn, squash, under pole beans, and at the base of tomatoes. This works well with clovers and oats.

25. Winter Cover Crop Calendar from *“Cover Crops for Home Gardens West of the Cascades”*
http://cru.cahe.wsu.edu/CEPublications/FS111E/FS111E.pdf

26. Spring and Summer Cover Crops can fill a niche between early spring crops, such as peas and lettuce, and late summer/fall crops like winter brassicas, winter greens, and garlic. Or can be planted instead of an early spring crop.

27. Harvesting Cover Crops:
- Mow or scythe when crop begins flowering, best for Nitrogen capture.
- Dig or till GREEN residue into the soil. Wait 3 or 4 weeks for decomposition before planting.

This provides a boost of N and OM for soil organisms, but disrupts the soil biota and aggregates.
- Use cut cover crops in your compost.
- Use cut cover crops for mulch.

• Allow cover crops to mature to seed. *You'll have seeds for your next planting, but will also provide an opportunity for cover crops to become weeds.*

• Leave the roots in the soil

28. Carbon and Calorie Crops: Feed yourself AND your soil by growing crops that provide both abundant carbon for your soil & compost, and calories for you. The seeds provide food, and the stalks (and roots!) provide carbon. These crops provide plenty of carbon for compost:

- **Rye**
- **Wheat**
- **Triticale**
- **Oats**
- **Barley**
- **Amaranth**
- **Quinoa**
- **Sunflowers**
- **Fava Beans,** to dry seed

Including cover crop legumes to harvest at early flowering stage will also provide Nitrogen for your compost. More information from **Grow Bio-intensive Gardening** *http://www.growbiointensive.org*

29. Feed and Protect Your Soil:

Feed: Maximize Biodiversity & Continuous Living Roots

Crop rotation
Cover crops
Biomass/forage planting
Perennial plantings
Pollinator & beneficial plantings
Organic fertilizers
Legumes in mix

Protect: Minimize Disturbance & Maximize Cover

Reduce tillage/digging
Dedicated beds and paths
Avoid digging or tillage when wet
No till
Mulching
Residue retention

"Give to nature, and she will repay you in glorious abundance"—Alan Chadwick

"When we clear or open a piece of soil, we have the responsibility to leave more life behind."
—Bob Cannard, Farmer