WOOD CHIPS AS A SOIL AMENDMENT

(Science-based strategies to enhance resilience to soil-borne pests and diseases)

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Micrograph of *Liriodendron tulipifera* (tulip-poplar) wood

OBSERVATION #1

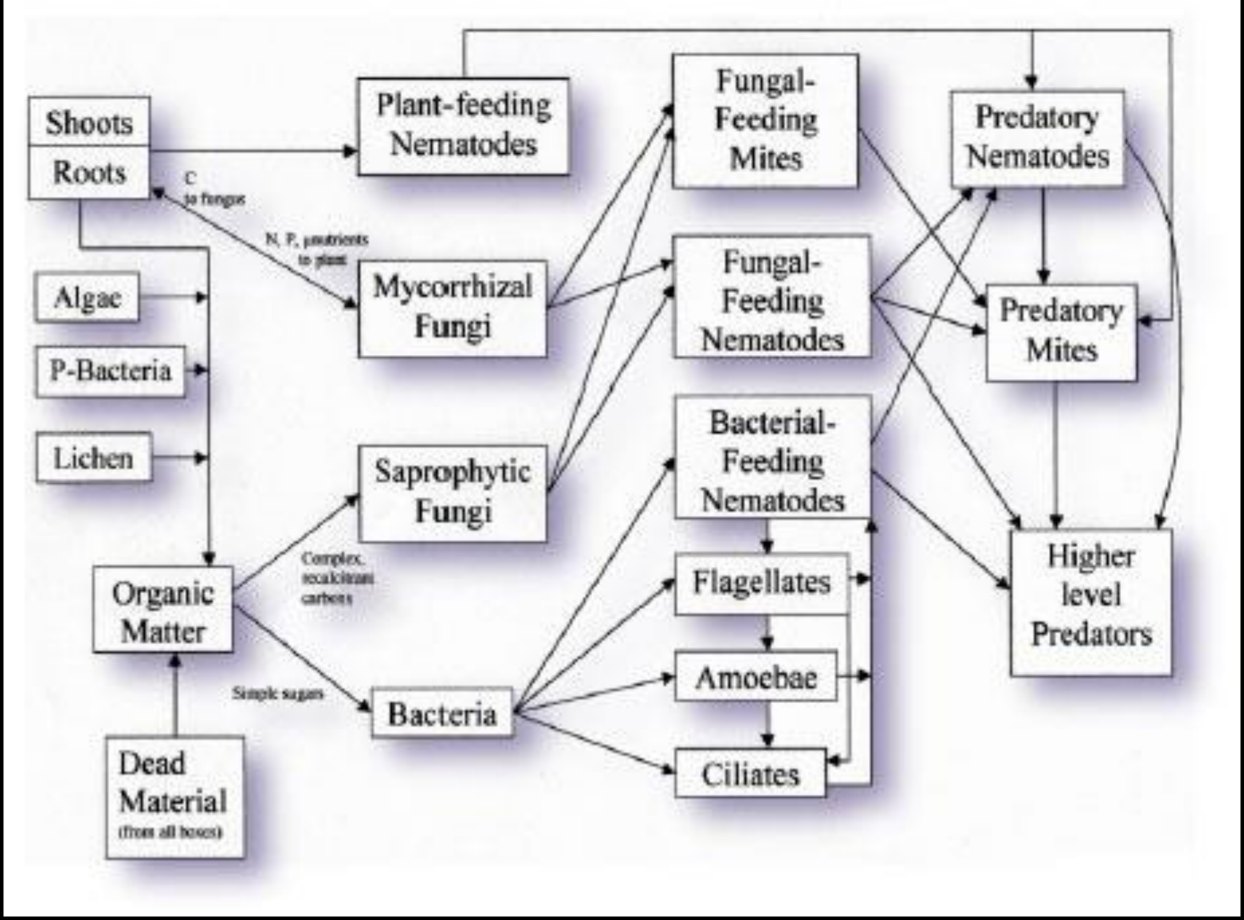
- ***Soil compaction and absent or weakly developed soilfoodwebs are often the main limiting factors for plant growth in urban areas***

- ***But these limiting factors are Off The Radar of most restorationists, gardeners, horticulturists…!***

SOILFOODWEB

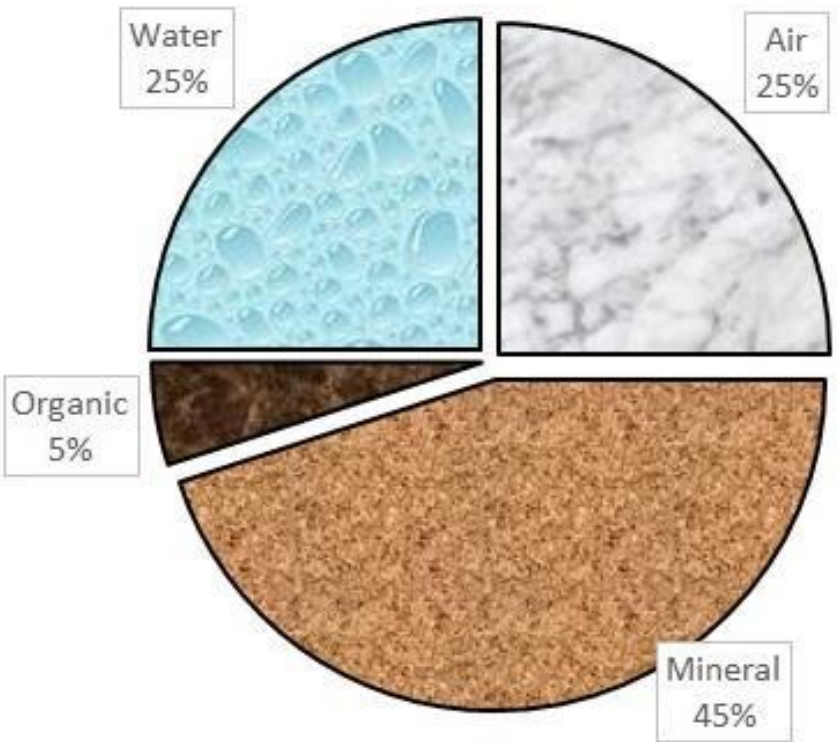
Bacteria, actinomycetes, basidiomycetes, archaea, protists, nematodes, arthropods (including spiders, mites, crustaceans, millipedes, centipedes), worms………… wee beasties

- **Residue decomposition**
- **Nutrient cycling**
- **Soil aggregation and porosity**
- **Contaminant transformation**
- **N-fixation**
- **Carbon sequestration**
- **Enhanced root function**
- **Pathogens**
- **Predators**

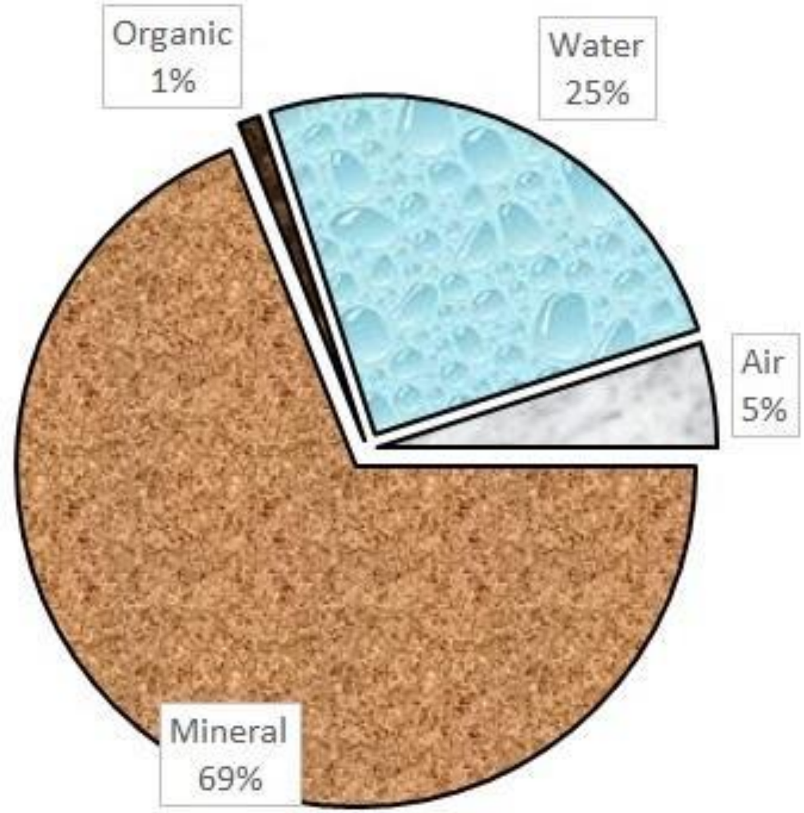


Urban / Suburban soils

- ✓ Compaction: Loss of structure and macropores
- ✓ Cuts: Loss of topsoil, less structure, shallow depth; deadened soilfoodwebs
- ✓ Fills: “dirt”



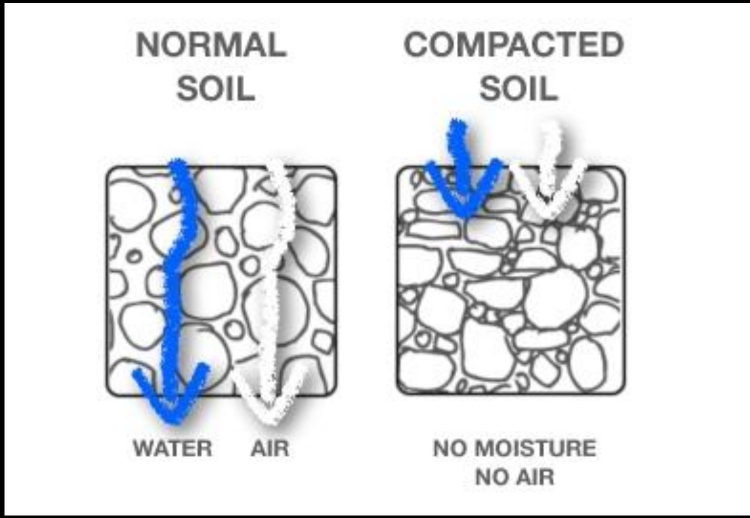
Ideal



Compacted

Effects of Urban Activity on Soils

- Increased bulk density (compaction)
- Resistance to root penetration
- Loss of structure
- Reduced porosity
- Reduced infiltration
- Reduced rooting depth
- Depauperated soilfoodwebs
- Reduced nutrient, OM, water availability



Consequences??

- Increased stress on plants
- Decreased plant vigor and survival
- Increased risk of erosion

Remedy??

- crop residues
- composts
- green manures
- mulches

ORGANIC MATTER!

WOOD CHIPS AS MULCH

commonly used for decades; a well-known, natural way to:

- support fungus-based soilfoodwebs
- suppress weeds
- conserve moisture
- increase soil OM
- minimize erosion
- buffer soil temperatures
- enhance the landscape aesthetic….

OBSERVATION #2

1. ***Current use of wood chips is based on misconceptions and very narrow understandings of the function of wood in and on soil.***

2. ***Greater strategic use of wood chips in ecosystem restoration and ornamental landscaping has the potential to importantly transform those PNW industries.***

OUTLINE

Benefits of using Wood Chips as a soil amendment:

- remediate soil compaction
- kick-start diverse soilfoodwebs
- increase soil nitrogen cycling and soil nutrient availability
- support healthy plant growth and enhance resistance to soil-borne pests and diseases

DEFINITIONS

MULCH: materials placed on the soil surface

SOIL AMENDMENT: materials incorporated into the soil profile to improve soil physical properties

MYTH

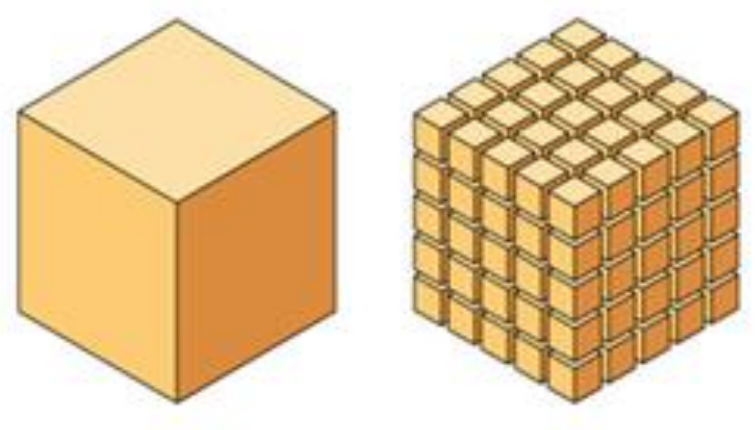
“Never mix wood into the soil; this creates a soil nitrogen deficit that adversely affects plant growth.”

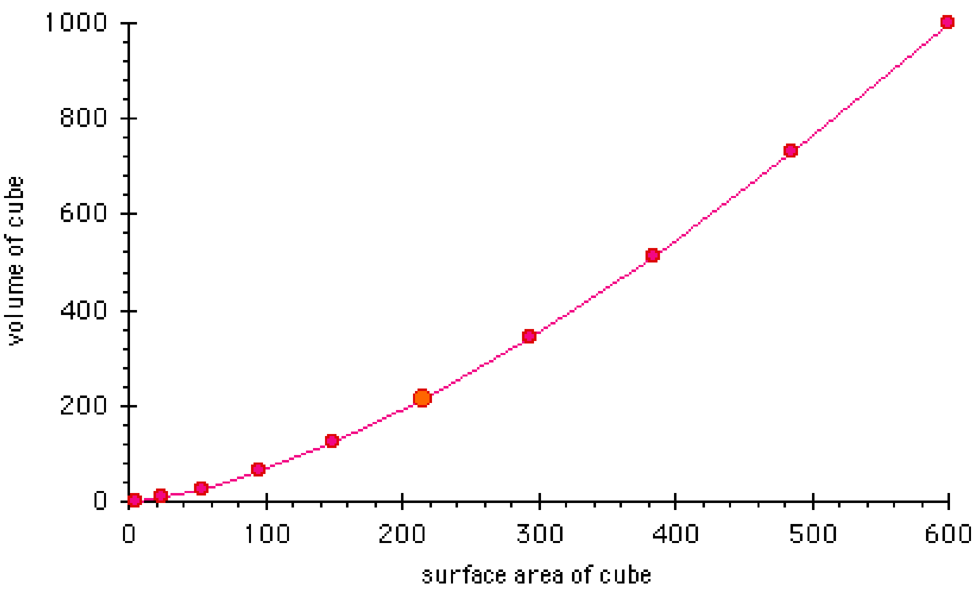
That'll rob soil nitrogen!

But….when you look for factual evidence of this phenomenon, it's difficult to find specific science-based information supporting this myth. Why?

CHIPS, NOT SAWDUST!

Graph the ratio of surface area to volume: as the size of an object increases (without changing shape), this ratio decreases. The denominator (volume) increases faster relative to the numerator (surface area)….





DEFINITIONS: WOOD

- Porous and fibrous structural tissue (secondary xylem) derived from inside of vascular cambia in stems and roots of woody plants
- Natural composite of cellulose (41-43%; crystalline) and hemicellulose (20-30%) fibers (strong in tension) embedded in a matrix of lignin (23-27%, resists compression)
- Rich in suberin, tannins, and other decomposition-resistant, compounds
- 50% carbon, 42% oxygen, 6% hydrogen, 1% nitrogen, and 1% other elements (mainly Ca, K, Na, Mg, Fe, and Mn) by weight, as well as S, Cl, Si, P, and other elements in small quantity

DEFINITIONS: BARK

- Porous and fibrous structural tissue (secondary phloem) derived from outside of vascular cambia in the stems and roots of woody plants

- Outermost layers of stems and roots of woody plants

- Consists of lignin (40%), biopolymers, tannins, suberin, suberan, and polysaccharides (cellulose) and other decomposition-resistant compounds

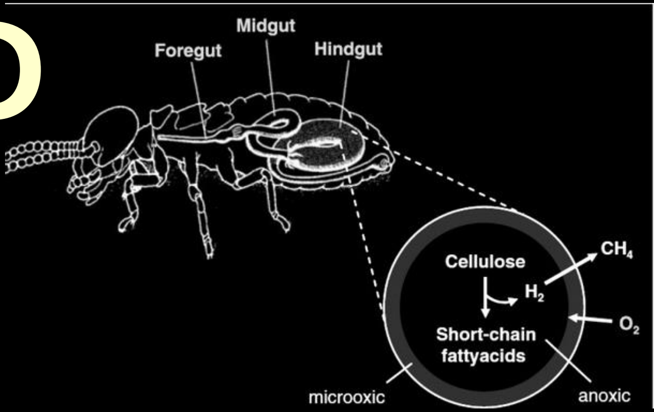
- Condensed tannins highly resistant to decomposition; more abundant in bark than wood

TABLE 1. Percentage of wood and bark carbon evolved as CO_2 in longtime experiments. Wood and bark ground into sawdust all passing through a No. 6 mesh (3.36 mm).
[Agricultural Research Service (1965)]

TREE SPECIES	PERIOD (days)	CO_2 EVOLVED, WOOD (%)	CO_2 EVOLVED, BARK (%)
Slash pine	365	28.3	12.2
Douglas-fir	580	37.9	40.9
Redcedar	800	34.6	50.2
White oak	580	65.3	54.7
Ponderosa pine	800	57.7	29.3

western redcedar essential oil contains many bioactive chemical: thujone; isothujone; fenchone; sabines; and α-pinen as main monoterpenes; plus acids and other constituents

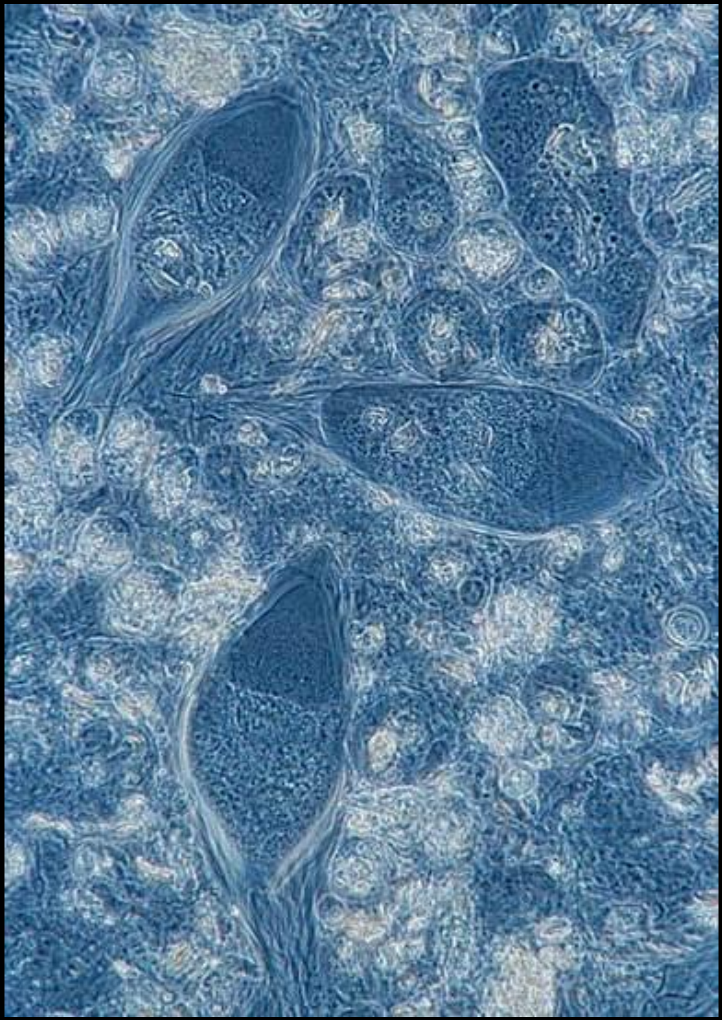
WHO EATS WOOD AND BARK??



Termites “eat” wood, but don’t digest it.

Protists (eukaryotes) in their guts ‘house’ digesters: *Trychonympha*, *Trichomitopsis*, *Streblomastix*

These wee beasties (protists) rely on other wee beasties [bacteria (prokaryotes)] inside their bodies to do the actual digestion!



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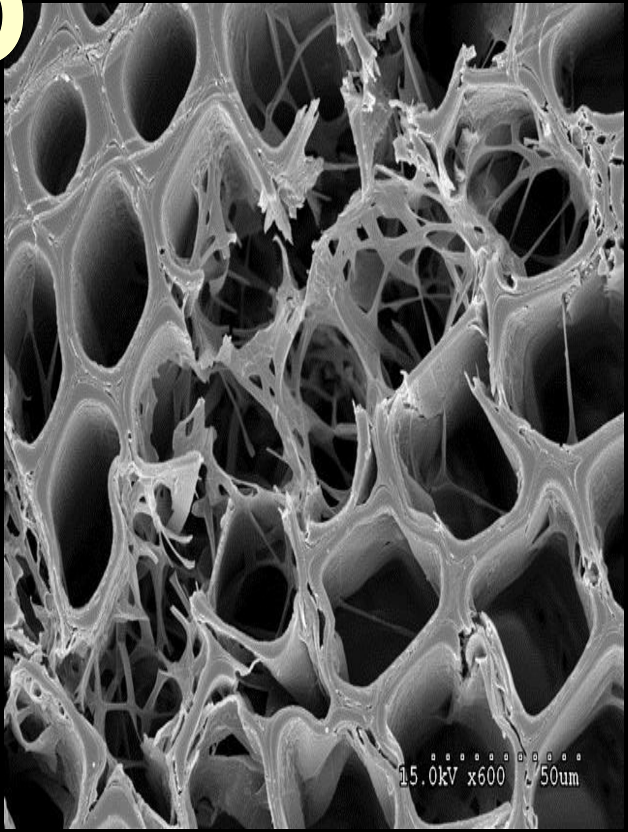


…and…fungi digest wood:

– **Enzyme-based digestion** (lignase, cellulase) (white rots)

– **Non-enzymatic, chelator-mediated (Fe) biocatalysis** (generates hydroxyl radicals) that results in hydrolysis (brown rots)

TYPES OF WOOD CHIPS

- <u>pure wood chips</u> e.g., chipped cedar for play areas
- <u>arborist wood chips</u>: leaves, bark, stemwood, and twigwood; materials vary in size / decomposition rate, creating a more diverse environment subsequently colonized by a diverse soil biota
- <u>ramial wood chips</u>: chipped TWIGS (not chipped stemwood/trunks) LESS than 7 cm in diameter; contains greater soluble or little-polymerized lignin, the base for soil aggregates and highly reactive humus; more than 75% of nutrients are stored in twigs

NATURAL ECOSYSTEMS DOMINATED BY WOODY PLANTS HAVE MUCH WOOD IN THEIR SOILS

- Tropical forests typically have the most robust carbon storage capacity on Earth: 360 to 460 metric tons of CO_2 equivalent/acre, compared to an average of 230 metric tons for PNW forests

- However, some Western Cascadian forests (e.g. Wind River old growth, Gifford Pinchot National Forest) have carbon stocks of more than 900 metric tons/acre.

NATURAL ECOSYSTEMS DOMINATED BY WOODY PLANTS HAVE MUCH WOOD IN THEIR SOILS

Tree Biomass Distribution (tons of dry weight/acre); HJ Andrews Experimental Forest (Grier and Logan 1977)

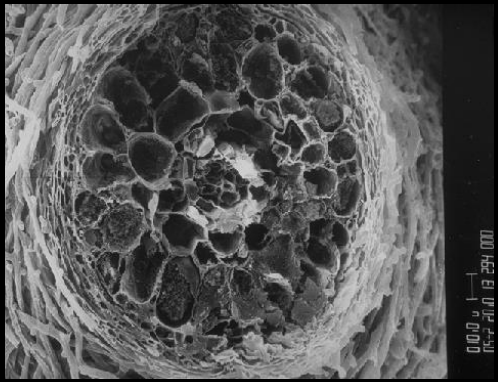
COMMUNITY TYPE	ABOVEGROUND TOTAL	BELOWGROUND TOTAL (ROOTS >5MM)
Pseudotsuga, Castanopsis (north slope; xeric)	297	59
Pseudotsuga, Castanopsis (south ridge; xeric)	435	86
Pseudotsuga, Rhododendron, Gaultheria (mesic)	219	43
Pseudotsuga, Rhododendron, Berberis (mesic)	360	71
Pseduotsuga, Acer, Polystichum (cool moist)	247	50

NATURAL ECOSYSTEMS DOMINATED BY WOODY PLANTS HAVE MUCH WOOD IN THEIR SOILS

Soilfoodwebs in woody plant ecosystems are dominated by fungi, many (most??) of which are mycorrhizal

Primary function of fungi appears to be that of wood decay: cellulolytic or ligno-cellulolytic

Their critical roles in building woody material through mycorrhizal associations, and destroying it through decomposition, allow fungal biomass in forest soilfoodwebs to reach 90% of the total—exceeding all other micro- and meso-organisms combined (Barron 2003)

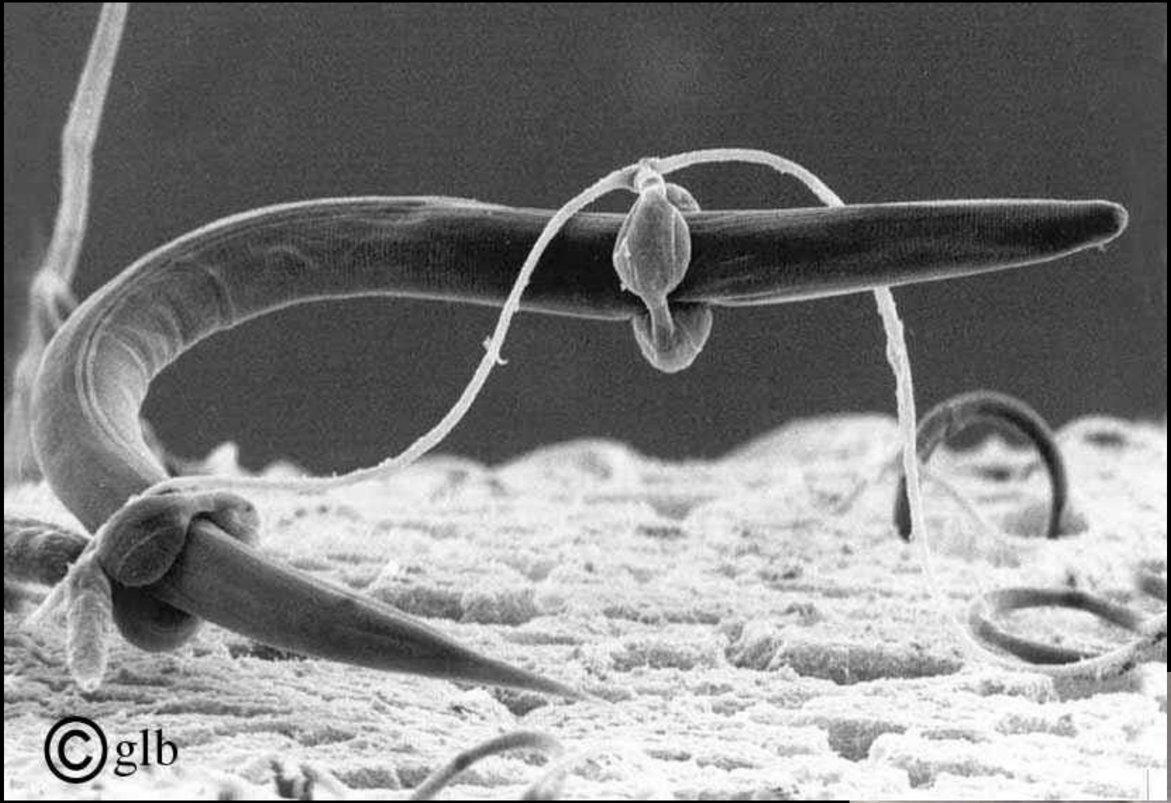


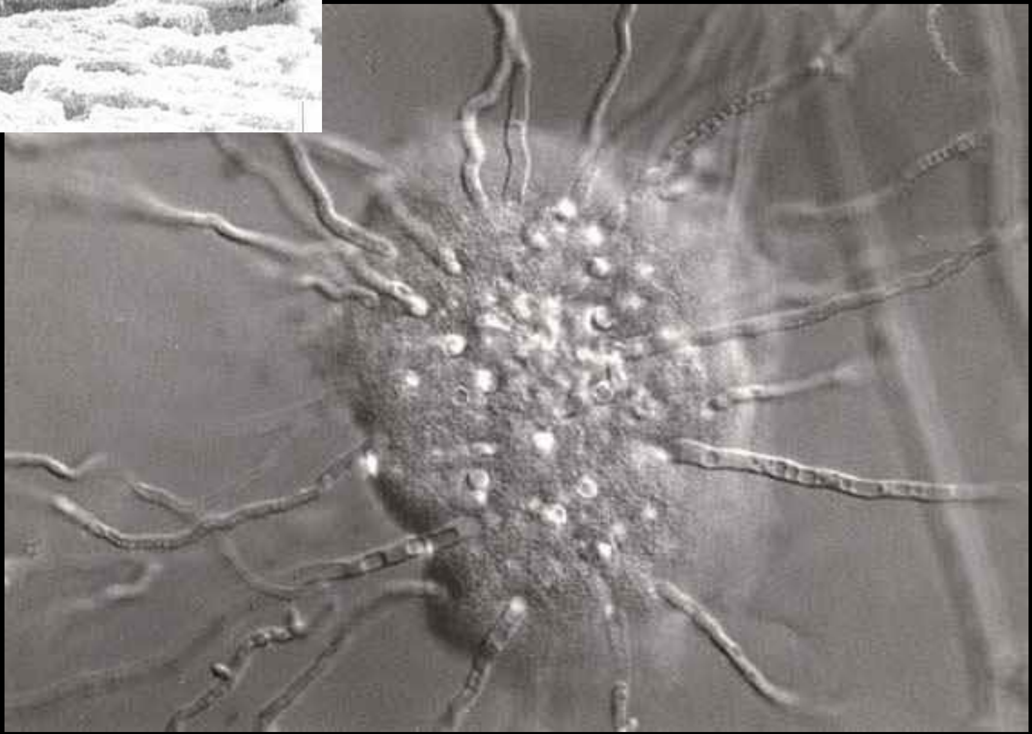
NATURAL ECOSYSTEMS DOMINATED BY WOODY PLANTS HAVE MUCH WOOD IN THEIR SOILS

- Fungi attack other organisms as sources of nitrogen to supplement a primarily carbohydrate (woody) diet. Carbon to Nitrogen ratio (C:N) of wood is extremely high and nitrogen can be a limiting factor for growth. For decay fungi, predation of nematodes or other organisms adds extra protein (nitrogen) to the system and reduces the C:N to ‘livable’ proportions.

- Nematode predation, although dramatic, is perhaps of less importance than the ability of wood decay fungi to attack bacteria and other life forms as nutrient supplements.

- ‘Parasitic’ phase runs parallel to the ‘saprophytic’ wood decay phase; both are essential to fungal success.





Carnivorous Fungi !

Klironomos and Hart (2001)

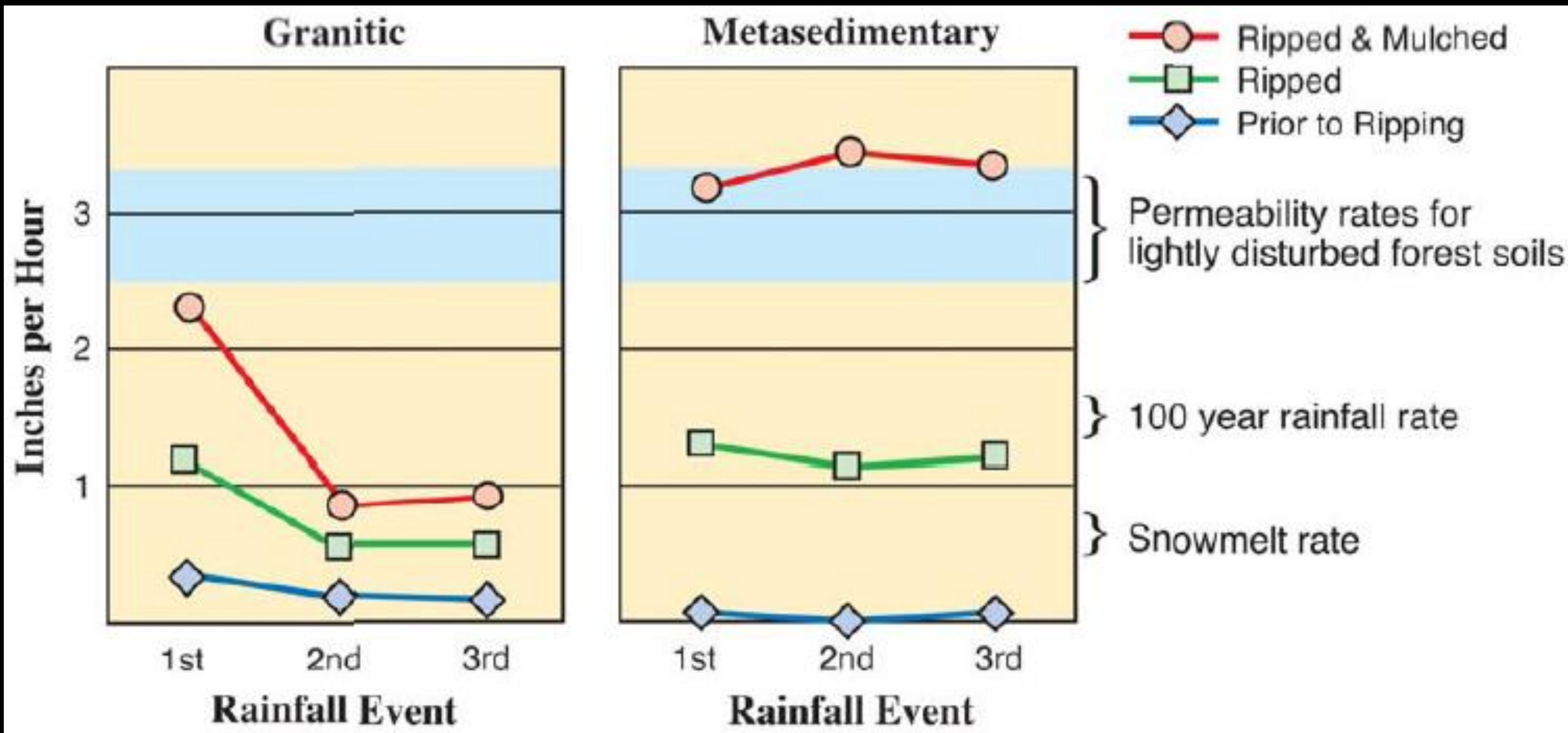
WOOD CHIPS MITIGATE SOIL COMPACTION

1. Soil productivity and physical characteristics are crucial to plant health and ecosystem functioning

2. Once compacted, soils take a very long time (if ever) to return to "pre-compaction" physical, chemical, and biological characteristics

3. Excessively compacted soils typically require physical intervention (mastication, ripping, or subsoiling) and incorporation of wood and other organic matter….

WOOD CHIPS MITIGATE SOIL COMPACTION



Coordinated Technology Implementation Program. Roadside Revegetation: An integrated approach to establishing native plants. http://www.nativerevegetation.org/

WOOD CHIPS MITIGATE SOIL COMPACTION: Drake 2015

Soil compaction increases as the number of vehicle passes increases. At three different North Tahoe sites:

- 6 passes with a rubber-tired harvester/forwarder led to 38-69% reductions in cone penetrometer depth-to-refusal (DTR); ‘
- 4 passes led to a 79% reduction in DTR (Highlands only);
- 2 passes led to a 3-32% reduction in DTR.
- Data suggest 4 to 6 passes was the threshold for lasting compaction at these sites (Highlands, Skylandia).

Soil resistance to compaction can be very site-specific:

- At Granlibakken, 1 to 3 passes by a harvester/forwarder led to a 67% reduction in penetrometer DTR, which was the same change in compaction measured at an adjacent plot with 5-10 equipment passes (65% reduction).
- Another plot at the same site with 50 to 100 passes resulted in the greatest compaction—an 83% reduction in penetrometer DTR

WOOD CHIPS MITIGATE SOIL COMPACTION: Drake 2015

- Adding 2-3 inches of wood chip mulch reduced runoff velocity by 60% and runoff distance by 54% compared to bare/unmitigated conditions

- Incorporating wood chips led to the same reduction in runoff velocity as mulching (60%) but a more substantial reduction in runoff distance of 85% due to higher infiltration rates

- Incorporating wood chips resulted in a 779% increase in penetrometer depth and a 230% increase in soil wetting depth during runoff simulation

- Treatments that do not improve soil physical structure (e.g. hydroseeding, mulching) temporarily reduce sediment yield; however, longer-lasting sediment reductions are associated with treatments that improve soil infiltration rates through loosening and soil amendment incorporation, which also support robust native vegetation.

- Road decommissioning treatments including soil loosening and wood chip incorporation…resulted in sediment reductions of more than 100 times (compared to untreated dirt roads) and foliar plant covers ranging from 3-18%. Three roads treated using these techniques resulted in NO RUNOFF and therefore no sediment yield, even at rainfall rates of 4.7 inches per hour

WOOD IS USED BY N-FIXING BACTERIA FOR FOOD AND SUBSTRATE

- Nitrogen-fixing bacteria significantly improve nitrogen availability in the soil. Bacteria called diazotrophs convert atmospheric nitrogen (N_2) into ammonia compounds that can be used by other organisms, including plants.

- Some plant species fix nitrogen with the help of *symbiotic diazatrophs* that live in root nodules (*Rhizobium* bacterium for Scot's broom; *Frankia* bacterium for alder)

Franki alni nodules on *Alnus glutinosa*. Photo by Cwmhiraeth - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21965251

WOOD IS USED BY N-FIXING BACTERIA FOR FOOD AND SUBSTRATE

- However, many bacteria (*asymbiotic diazatrophs*) live in the soil and fix significant levels of N without directly interacting with other organisms: *Azotobacter, Bacillus, Clostridium, Klebsiella…*

- These organisms must find their own substrate and source of energy, typically by oxidizing organic molecules released by other organisms or from decomposition

- Because nitrogenase is inhibited by oxygen, free-living organisms behave as anaerobes/microaerophiles while fixing N

WOOD IS USED BY N-FIXING BACTERIA FOR FOOD AND SUBSTRATE

Because of the scarcity of suitable carbon and energy sources for these organisms, their contribution to global nitrogen fixation rates generally has been considered to be minor.

- However, a recent Australian study of an intensive wheat rotation farming system demonstrated free-living N-fixing diazatrophs contributed 18 lbs/ac/year to the long-term nitrogen needs of this cropping system—30-50% of the total needs (Vadakattu and Paterson 2006).
- **Maintaining wheat stubble and reduced tillage in this system provided the necessary high-carbon, low-nitrogen environment to optimize activity of asymbiotic diazotrophs.**

WOOD IS USED BY N-FIXING BACTERIA FOR FOOD AND SUBSTRATE

Unmanaged second-growth *Tsuga heterophylla, Abies amabilis* forest type and a *Thuja plicata / Tsuga heterophylla* old-growth forest; northern Vancouver Island, BC, Canada:

- Estimates of nitrogen fixation ranged from 0.9 to 1.9 lb N/acre/year, the magnitude of these values depending more on the mass of coarse woody debris substrate available for asymbiotic N-fixing bacteria than on differences in nitrogenase activity rates (Brunner and Kimmens 2003).
- Among the highest rates reported in the literature.

WOOD IS USED BY N-FIXING BACTERIA FOR FOOD AND SUBSTRATE

Scientists have recently discovered another nitrogen fixation mechanism in plants!

- *Klebsiella* strains have been isolated from rhizosphere of many plants; these bacteria are called associative nitrogen fixers because they are diazotrophs that colonize root surfaces (Haahtela et al. 1986)

- Recent data suggests some diazatrophs fix nitrogen as plant endophytes (in plant tissue but not in cells) (Iniguez et al. 2004). This nitrogen fixation capacity is suspected to be strongly species-species specific.

- Cottonwoods, willows, Gunneraceae, grasses, *Azolla*, cycads, liverworts… every plant?

- Endophytic bacterial communities can be remarkably diverse, with reports of 53 (Ulrich et al. 2008) and 78 genera (Taghavi et al. 2009) in poplar, willow.

WOOD KICK-STARTS DIVERSE SOILFOODWEBS AND SUPPORT HEALTHY PLANT GROWTH

- Occurrence of pathogenic bacteria is low in healthy plant populations.

- Plant defense systems are selective and cause enrichment of plant-beneficial microbes in the rhizosphere. Such beneficial bacteria include saprophytes that degrade organic matter, plant growth promoting rhizobacteria, and antagonists of plant root pathogens (Barea et al. 2005).

WOOD KICK-STARTS DIVERSE SOILFOODWEBS AND SUPPORTS HEALTHY PLANT GROWTH

Craig Kohlruss, The Fresno Bee

Incorporating wood chips is a technique being promoted in orchard renovation in California (over orchard burning or sale of biomass for co-generation).

"…*soil incorporation of chipped or ground almond, peach, plum, or cherry trees during orchard removal could provide an alternative to co-generation plant or burning and could add valuable organic matter to our San Joaquin Valley soils. Traditionally, many growers feared that wood chips or grindings would stunt tree growth by either allelopathic compounds or reduced nitrogen availability due to the high C:N ratio. (R)ecent research has found this not to be true if the ground material is spread across and incorporated into the soil.*" Brent Holtz (UCCE San Joaquin) and David Doll (UCCE Merced); http://thealmonddoctor.com/2015/11/14/whole-orchard-soil-re-incorporation/

WOOD KICK-STARTS DIVERSE SOILFOODWEBS AND SUPPORT HEALTHY PLANT GROWTH: Holtz et al. 2014

Soil analysis revealed significantly more Ca, Mn, Fe, Mg, B, Cu, nitrate, electrical conductivity, OM, total C, organic carbon; and significantly reduced soil pH

Did not stunt replanted tree growth

Greater yields

"Iron Wolf," a 50 ton rototiller

Tissue analysis showed significantly greater levels of N, P, K, Mn, and Fe while Mg and Na levels were significantly lower

Wood chips stimulate the microbial activity (bacteria and mycorrhiza), which provides the nutrients (N, P, etc. via mineralization) and organic carbon to soil

Less salt burn and less wilting when water was cut-off for harvest, suggesting increases in cation exchange and water holding capacity

ADDITIONAL BENEFITS OF WOOD IN/ON SOIL

- Provide surface and subsurface microtopography, microclimate, microhabitat…
- Water reservoirs, which leads to moderation and stabilization of soil temperatures, both of which benefit plants and soil organisms
- Physically mitigate soil hydrophobia
- Enhances soil carbon sequestration
- Wood delivers additional nutrients; nutrient sequestration increases as soil biomass builds from wood as a food source

GENERAL CONCEPTS: WOOD IN/ON SOIL

- Talking about the coarse wood component of soils
- Decay of coarse wood is slow; beneficial effects may last for decades or centuries
- Nitrogen not usually a limiting factor in PNW soils
- No inoculations needed: fungal spores and bacteria are everywhere (though not well-documented)
- Numerous studies demonstrate losses in soil productivity are closely linked to losses in soil OM
- Restoring natural levels of coarse wood incorporated into soil horizons may be intensely long-term process
- There’s a lot we don't know yet. Hey, it's complicated!

HUGELKULTUR
(hill culture or hill mound)

- no-dig raised beds designed to hold moisture, build fertility, maximize growing surface area…
- great spaces for growing fruit, vegetables, herbs….

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Klironomos, J.N. and M.M. Hart. 2001. Animal nitrogen swap for plant carbon. Nature 410: 651-652. (*Pinus strobus*) ("ectomycorrhizal plants can indirectly depredate soil arthropods [primarily collembolans (springtails)] for a significant source of nitrogen through their fungal partners." More than 25 percent of a tree's nitrogen may come from soil insects consumed by carnivorous mycorrhizal fungi!)

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