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Putting Carbon in its Place:

A Gardener's Guide to Sequestration

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Healthy Soil=Healthy Vibrant Plants

A Biologically healthy soil rich in microbial life:

- Produces vegetables with a higher nutrient value.
- Produces flowers & vegetables with more vibrant colors, and a longer shelf life.
- Produces flowers & vegetables with more intricate & intense flavor & aromas.
- All the while removing CO2 from the atmosphere and sequestering it deep in the soil.

Soil Carbon

- Soil organic carbon (SOC)—carbon that derives from organic materials and is stored or sequestered in soil—accounts for approximately 58 percent of the total organic mass found in soil. It is the largest global pool of terrestrial carbon.
- Every 27 tons of carbon sequestered biologically in soil represents 100 tons of carbon dioxide removed from the atmosphere.
- Historic levels of soil organic carbon far exceeded modern-day levels. Down over 50- 70%.
- Over 790 billion tons of carbon emissions from 1750 to 1999 can be attributed to the loss of SOC.
- By bringing buried SOC to the surface, tilling accelerates the rate of decomposition and carbon dioxide exhalation.

- Rodale Research Center

Carbon Sequestration

- Atmospheric carbon levels can be lowered through our growing practices!
- The soil's capacity to sequester carbon is determined by plant root depth, plant photosynthetic rate and soil biology.
- Soil Organic Matter (SOM) –surface carbon-eventually decomposes which is good for the soil food web but leads to the formation of CO2.
- "Humus,(SOC) on the other hand, is formed by soil microbes within soil aggregates, from sugars channeled to soil via the hyphae of mycorrhizal fungi living in association with actively growing green plants.
- "Once formed, humus is an inseparable part of the soil matrix and can be very long-lived (as in hundreds of years). Hence it fulfills the requirements for safely removing excess CO2 from the atmosphere and storing it in soil." Dr Christine Jones http://thenaturalfarmer.org/article/soil-carbon-some-frequently-asked-questions/
- Carbon is sequestered at greater depths in no-till systems than tilled systems. The extended root production, along with the increased soil macro- and microbiological life, sequesters the carbon deeper in the soil. " J. Moyer, Rodale Research Center

Soil Microorganisms

- A teaspoon of healthy/biological soil contains billions.
- Most common: bacteria, fungi, protozoa, nematodes, & arthropods.
- Without microbes, we wouldn't eat.
- Play a key role in soil fertility by recycling nutrients and making them bioavailable.
- Most microbes need organic carbon to live; they get this from eating wood chips, leaves, manures and other decomposing organic materials the soil.
- They also get carbon from the rhizosphere (the area immediately around plant roots) because roots give off substances (root exudates), like sugars and amino acids that the microbes can use.
- Then convert some of these exudates back into forms the plants can use, such as minerals, vitamins, nitrogen, oxygen, hydrogen, phosphorus, potassium, amino acids and trace minerals.

Bacteria

- Among the first organisms to begin decomposing residues in the soil.
- Perform important services related to water dynamics, nutrient cycling, and disease suppression.
- Synthesize hormones, fix nitrogen, produce fungicides & antibiotics for plants on demand.
- Some affect water movement by producing substances that help bind soil particles into small aggregates.
- Convert energy in soil organic matter into **forms useful to the rest of the organisms in the soil food web thus b**enefiting plants by increasing nutrient availability.
- Nitrogen Fixation: some types are able to take nitrogen gas from the atmosphere and convert it into a form that plants can use.
- Need food rich in nitrogen (e.g. green manure, legume residues); a fertilizer rich in nitrogen therefore favors the bacterial community.
- More abundant in tilled soil

Fungal Mycelium

- Fungal hyphae grow in long thin strands-mycelium.
- Dominate most soils in the temperate climate.
- Are the predominant cellulose decomposers, flourish with high C:N ratio.
- Derive their carbon and energy requirements from the break down of dead and decaying plant cell walls-cellulose and lignin.
- Symbiotic relationship with most plants (excepting brassicas) help plants take up water and nutrients, improve nitrogen fixation by legumes.
- Vast nutrient transport system.
- Roots that have lots of mycorrhizae are better able to resist fungal diseases, parasitic nematodes, drought, salinity, and aluminum toxicity.
- Vast communications network
- Help form & stabilize soil aggregates.
- More abundant in untilled soil.

Glomalin

- Discovered by Sara Wright in 1996
- A glycoprotein produced by mycorrhizal fungi is a highly stable form of soil carbon.
- A soil glue- binds soil particles together building & stabilizing aggregates.
- Gives soil it's tilth/texture.
- Stores Carbon (30-40%) & Nitrogen.
- Accounts for 27% of Carbon in soil & is major component of Organic Matter.
- Lasts over 40 years.
- Improves water storage capacity

No-Till

- A method of growing that eliminates turning garden soil by plowing, rototilling, or other use of machines or hand tools, thus keeping the soil profile intact

No-Till Methods

Solarization: trapping the sun's radiant energy to kill unwanted vegetation, especially newly germinated and sprouted weed seeds.

- Spread light-weight **clear** plastic over bed.
- Weigh down edges.
- Sunny day so heat builds-up.
- Leave on 24 hours (48 maximum); more will damage soil microorganisms.

Occultation: preventing the sun's rays from hitting the soil, trapping warmth and moisture encouraging weed seeds to germinate and sprout into a darkened "unfriendly" environment where they die and become food for worms etc.

- Cover bed with an opaque barrier- tarps, cardboard….
- Weigh down the edges
- Leave covered for 3-6 weeks or as long as necessary.
- Will not break-down large amounts of plant residue or persistent perennial weeds.

No-Till Methods

continued

"**Lasagna Method"**: a way to create new garden beds without turning or preparing existing soil.

- Lay down large pieces of cardboard on designated area. Make sure to overlap so all is fully covered.
- Add layers of organic matter: rotted hay, shredded leaves, manure, compost…..with top layer of straw or wood chips to help keep other layers from drying out.
- Keep watered- moist but not sopping.
- Will create fantastic soil as worms and other microorganisms love the cardboard.
- Wait 6 months and plant directly.
- Plant sooner by making planting holes and filling with compost/top soil .

Mulch: keeping soil covered at all times. which contains moisture and suppresses weeds.

- Use biodegradable materials: rotted hay, straw, wood ships, shredded leaves, cover crop cuttings,, burlap…
- Allows for moisture penetration but helps prevent evaporation.
- Suppresses weeds.
- Prevents erosion.
- Moderates soil temperature.
- Constantly decomposes, feeds microbes, worms,.. And becomes soil.

Cover Crops/Green Manures

Cover Crop: Growing a crop of grass, small grain or legumes primarily for seasonal soil protection and soil improvement.

As cover crops grow, they become reservoirs for important plant nutrients such as nitrogen, phosphorus and potassium, as well as micronutrients.

Green Manure: a herbaceous planting used as a fertilizer crop, grown and then intentionally plowed under while green to enrich the soil.

Cover Crop

- Longer term soil improvement.
- Wait to cut until seed set, but not mature.
- Leave residue on top of soil to decompose & serve as mulch.
- Decomposition of ligneous material increases mycorrhizal fungal activity
- Creates larger root mass.
- More liquid carbon (carbon compounds exuded by roots) dumped into soil.

Green Manure

- Shorter term soil improvement.
- Cut when young (up to 4 “), use solarization or occultation to kill rather than turn under.
- Big nutrient boost, especially N.
- Microbial digestion stabilizes nutrients in soil.
- Wait 2 weeks before planting vegetable crop.
- Waiting also allows for decrease in allopathic reaction

Benefits

Cover Crops

- Builds Healthy Soil: improves texture, increases water retention, microbial booster, nutrient enhancer, nitrogen fixer, increases fertility, increases organic matter.
- Improves Soil Structure: roots make air & water pathways, increases fungal growth which increases glomalin production enhancing crumb & building soil aggregate.
- Weed Suppression: smothers weed see; has an allopathic (biochemical) effect on weed seeds prevents germination.
- Erosion Control: water retention, decreases run-off & nutrient leaching.
- Biomass Producer: use for mulch or compost.
- Living Mulch.
- Pest & Disease Control.
- Carbon Sequestration.

No-Till

- Does not disrupt soil profile: improves texture, increases water retention/air penetration, enhances crumb, builds aggregate.
- Slows the breakdown of organic matter resulting in a slow steady release of nutrients.
- Creates beneficial environment for soil organisms: earthworms, bacteria, fungal hyphae….
- Weed Suppression: dormant weed seeds not brought up to optimal growing conditions.
- Erosion Control: water retention, decreases run off & nutrient leaching.
- Carbon Sequestration: exposes less organic matter to surface.

Planting strategies

Full Season Planting

- Designate beds/areas to be full season cover crops.
- Either one crop/cocktail to maturity, may let it re-sow itself.
- &/or under-sow with other CC's. (April/May- sow oat/pea/radish; June/July- add buckwheat/sorghum
- Or cut & regrow for bio-mass.
- Sow as vegetable crop is removed (lettuce, garlic…)
- Sow any bare soil or through mulch

Succession & Under-sowing

- Sow early and cut to kill/crimp then plant late season crops (nightshades, cucurbits…)
- Fill-in bare spots as occur
- Under-sow taller crops in mid-late season when 1/3 way through vegetables' growth cycle up until 4 weeks before killing frost. (i.e. Corn with 75 day maturity, under-sow after it is 25 days growth); Tomatoes, peppers, pole beans, asparagus…
- Use as shade/protection

Maintenance of Cover Crops

- Broadcast/sprinkle seed on bare ground and rake-in
- Same through medium/light mulch- so seed contacts soil
- Water until germination
- Cut as needed- Japanese sickle, clippers, or whatever you have.
- Crimp- use hands, pipe, board drag to bend and crimp stalk.
- No- Till tools: broadfork, garden fork to loosen/fluff/aerate without turning.
- To kill: cut at or below soil level; crimp (bend stalks to interrupt plant vascular system) at soil level
- To cut-come again: cut 2-4 inches above soil
- For bio-mass: cut just before plant maturity- use for mulch or add to compost
- Let go to seed: self-reseeds the bed or collect & save seeds for later planting

Types of Cover Crops Useful For Small Scale Growing (using hand tools)

- Oat & Field Pea: 2 to 3 feet tall, hardy to 10 to 20°, for early or later planting, winter kills
- Buckwheat: tender, plant after frost, plant thickly for weed suppression, good for beneficial insects/ pollinators
- Sorghum/Sudan Grass: 3-6 feet tall, biomass producer, good for increasing carrot yield, winter kills.
- Radish: breaks up hardpan, bio accumulator, winter kills
- Clover: living mulch, overwinters, nitrogen fixer, good for path ways – perennial, so harder to manage

Soil Building, Winter Kill Cover Crops

Oat & Field Pea

- Love them!
- Can plant early and through out summer.
- Great weed suppression; soil builder; bio-mass for mulch, N producer.
- Cut 2” above soil & regrow or cut at/below soil & kill.
- Winter kills creating soil protecting mulch.

Buckwheat

- Short season annual use as “short window”opportunity.
- Suppresses weeds.
- Short fibrous roots.
- Improves soil aggregate.
- Scavenges & makes available phosphorus and calcium.
- Seed June- Aug. or later.
- Cut before maturity to prevent volunteers.
- Attracts beneficial insects.

More Soil Building, Winter Kill Cover Crops

Sorghum/Sudangrass

- Midsummer “grass”.
- Heat & drought tolerant.
- Biomass- root and top.
- Increases Organic Matter
- Suppress root knot nematodes.
- Seed June- mid Aug.
- Cut back at 20-30” to 6”. Use for mulch.
- Cut before winter and leave on soil.
- Plant prior to carrots

Forage Radish

- Daikon type
- Deep subsoiler- breaks up hardpan
- Creates water & air pathways
- Large leaf foliage smothers weeds

Other Useful Winter-kill CC's

- Barley-fast growing, draught tolerant, scavenges excess nutrients, increases organic matter, not good in wet soil, 2 to 3 feet tall, hardy 0 to 10° F., fast maturing.
- Crimson Clover-N source spring or fall, prevents erosion, good between rows/beds, soil builder, ground cover, robust roots, bio-mass, pollinator attractant.
- Sunflowers- nutrient accumulator, attract pollinators,
- Sunn Hemp-fast-growing, N fixer, reduces weeds, reduces erosion thrives in poor soil, heat/draught tolerant, bio-mass producer, suppresses parasitic nematodes, pollinator attractant.

Useful Perennials

Dutch White Clover

- White Dutch and Red Clover
  July 2
- White is a slow growing N fixing perennial
- Self seeds and spreads by creeping and growing roots.
- Good for living mulch
- Handles traffic; good for paths.
- Seed: alone or with oats; early spring; mid Aug- mid Sept

Medium Red Clover

- Short lived perennial.
- Nitrogen fixer
- Self seeds easily; may use nurse crop of oats
- Plant no deeper than ½”
- Cut & use as mulch for increased nitrogen and organic matter.
- Tap roots break up compaction
- Weed suppression

Cover Crop Cocktails

- Mix many seeds together.
- Diversity increases effectiveness
- Mix for desired outcome: - winterkill, perennial, weed suppression, root depth….
- Mine: oat, pea, buckwheat, forage radish
- New for 2018- adding barley, sunn hemp, crimson clover and sunflowers to the mix.

Remediation

Foliar Tea: For Extra Boost of Nutrients & Biological Reinforcements, Spray as Needed

- Add to bucket: mix of vibrant plants to obtain their nutrients, hormones, enzymes, minerals, & vitamins (red clover, comfrey, nettles, vetch, oat grass, garlic….)
- Cover with water
- Sit in sun for a day or two
- Strain and add: liquid fish & liquid sea weed as per labels
- Spray plant foliage (underside of leaves best)- if possible "when birds are singing", stoma are open.
- Helps boost living/biological systems on leaf surface
- Backpack, or hand sprayer

Poor or Depleted Soil?

Might need to re-mineralize- adding mineral supplements until soil biology can take over. (purchased, or from local quarries)

- Add soil biology from a healthy wooded area.
- Foliar feed more regularly adding minerals and more trace minerals.
- Cover Crop intensively.
- Add compost, composted manure.
- Ligneous mulch, ramial wood chips, cardboard.

Adding Mycorrhizal Inoculants

- Jump start your fungal symbioses
- Gather from the wild- under healthy forest trees
- Soil from healthy garden
- Purchase inoculants for: seeds, transplants, roots, soil drench, foliar.
- Michael Phillips list

MYCORRHIZAL WHEREWITHAL

Companies that offer righteous inoculum for making the world a more fungal place.

BioOrganics	www.bio-organics.com
Fungi Perfecti	www.fungi.com
Horticultural Alliance	www.horticultural alliance.com
Mycorrhizal Applications	www.mycorrhizae.com
Reforestation Technologies International	www.reforest.com
Soil Symbiotics	www.soilsymbiotics.com
Aurea (Germany)	www.mycorrhizaworld.de /hp2/Homepage.htm
Premier Tech (Canada)	www.ptagtiv.com/en

Cornell University Suggested Rates

seeding rates in square feet or acres	net pounds							
	1/4	1/2	1	4	8	20	25	50
Annual Ryegrass	700sf	1400sf	2900sf	1/84A	1/2A		1.5A	
Buckwheat	200sf	400sf	800sf	3400sf	6800sf		1/2A	
Hulled Oats	250sf	500sf	1100sf	4400sf	1/4A		2/3A	
Lacy Phacelia	1200sf	2400sf	4800sf	1/2A	3/4A			
Sunn Hemp	700sf	1400sf	2800sf	1/4A	1/2A		1.5A	
Crimson Clover	500sf	1000sf	2000sf	8000sf	1/3A		1A	
Taproot Radish	1300sf	2700sf	5400sf	1/2A	1A		3A	
Austrian Winter Pea	200sf	400sf	800sf	3300sf	6600sf		1/2A	
Hardpan Drill	1300sf	2700sf	5000sf	1.2A	1A		3A	
Spring Green	375sf	750sf	1500sf	6000sf	1/4A		1A	
Winter Cover	300sf	600sf	1200sf	4800sf	1/4A		2/3A	
New Garden	350sf	700sf	1400sf	5800sf	1/4A		3/4A	
Boost Fertilizer			25sf	125sf		500sf		1250sf

These rates are at minimum seeding rates. You can add in more for denser results.

Helpful Resources

- NOFA Mass Soil Technical Assistance
https://www.nofamass.org/soil-technical-assistance-program

- NOFA/Mass Bulk Order (January)
https://www.nofamass.org/bulk-order-program

- Logan Labs- soil tests, http://www.loganlabs.com/

- Lancaster Ag- amendments, inoculants
http://www.lancasterag.com/SOIL-NUTRIENTS/folder/141

- John Kempf – inoculants, amendmentshttps://www.advancingecoag.com/regenerative-agriculture-products

- Others?

Bibliography

- http://thenaturalfarmer.org/article/mycorrhizal-fungi-powerhouse-of-the-soil/
- http://www.nofamass.org/carbon
- http://www.nofamass.org/content/carbon-resources
- http://covercrops.cals.cornell.edu/index.php
- http://www.nps.ars.usda.gov
- SARE- Sustainable Agriculture Research & Educationhttp://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops
- http://notillveggies.org/cover-crops-for-no-till/cover-crop-niches/
- Interesting details from Penn State on soil health and cover crops
- http://extension.psu.edu/publications/ee0174/view
- http://extension.psu.edu/publications/ee0026/view
- http://www.motherearthnews.com/organic-gardening/cover-crops-improve-soil-zmaz09onzraw.aspx
- The Natural Farmer (NOFA); Cover Crop issue & Carbon Sequestration issue.
- Many NOFA/Mass Soil and Nutrition Conferences
- Prof. Geoffrey Davies; g.davies@neu.edu
- Wild Browse Farm & Sustainability Center Wendell, MA 01379 http://wildbrowsesustainability.com

What will YOU do?

- Take a minute to think and write down 3 things you might want to implement in your garden.
- This year?
- Next?
- Please share.