What's the News from Organic Soil Health Research?

Practical Applications for Your Farm

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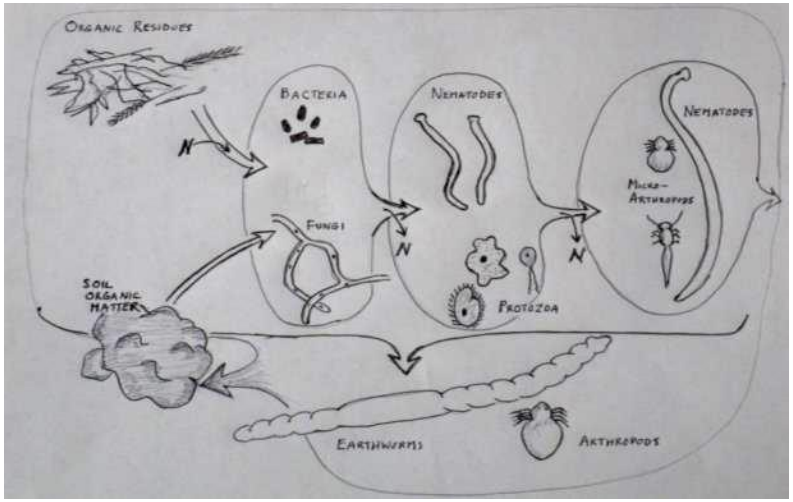
ORGANIC FARMING RESEARCH FOUNDATION

Healthy, Living Soil is the **Foundation** of ~~Organic~~ ***all*** **Successful Farming**

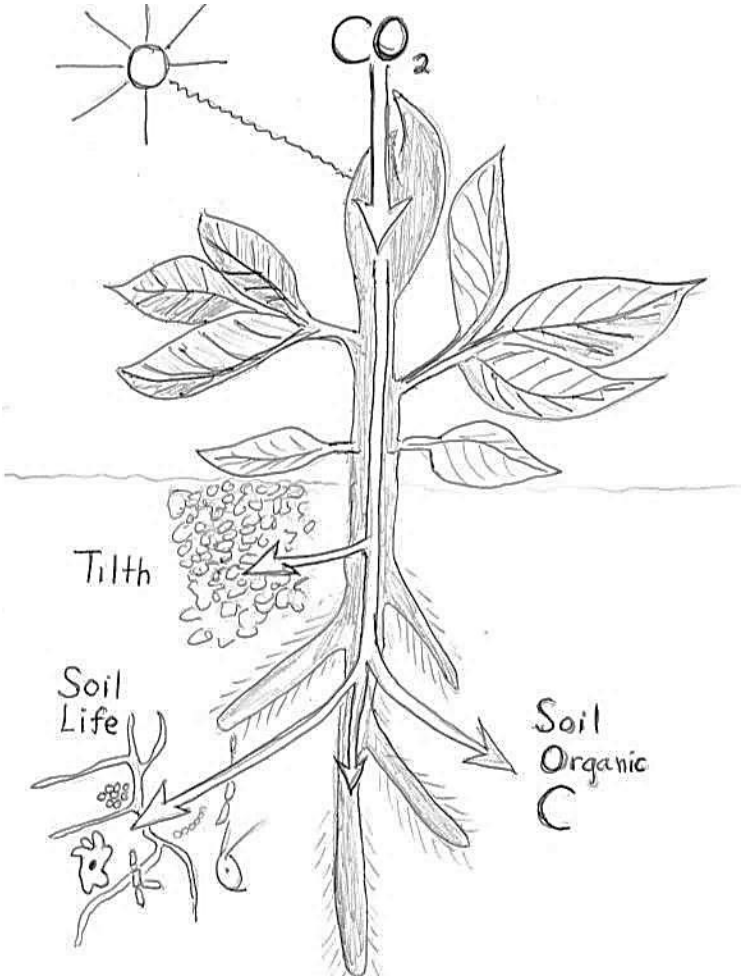
- VABF farmers David (in photo) and Lee O'Neill at Radical Roots Farm make a living growing great vegetables on five acres.
- Their healthy soil is a living system, with an abundant, diverse, and functionally integrated soil food web.



What is Soil Health? Healthy soil:

- Has high organic matter relative to texture and climate.
- Supports satisfactory yields of high quality crops.
- Maintains good tilth, drainage, aeration; resists erosion.
- Can absorb, hold, and provide moisture, reduces runoff.
- Enhances nutrient cycling and nutrient use efficiency.
- Is resilient – sustains yields in “bad” years.
- Protects water quality by minimizing nutrient losses.
- Sequesters carbon (C).
- Can suppress diseases, reduce weed and pest problems.
- *Sustains or enhances these qualities year to year.*

How do we maintain soil health?



The living plant is the farmer's primary tool to build and maintain soil health and fertility.

Maximize year round:

- *Living plant cover*
- *Plant biomass*
- *Active root and top growth*

The living plant is also Nature's primary tool for building soil.

Plants and trees protect the soil, recycle nutrients, replenish organic matter, and feed the soil food web via root exudates.

NRCS Soil Health Initiative

Four Principles of Soil Health Management

- *Keep soil covered as much as possible.*
- *Maximize living roots throughout the soil profile.*
- *Minimize soil disturbances:*
  - Physical – tillage, traffic
  - Chemical – soluble fertilizers, herbicides, pesticides
  - Biological – overgrazing, invasive exotic species
- *Energize the soil system with biodiversity.*
  - *Crop rotation, intercropping, multispecies cover crops*

Based on the work of the NRCS Soil Health Team in Greensboro, NC – David Lamm, Ray Archuleta, Steve Woodruff, and Terry Briscoe

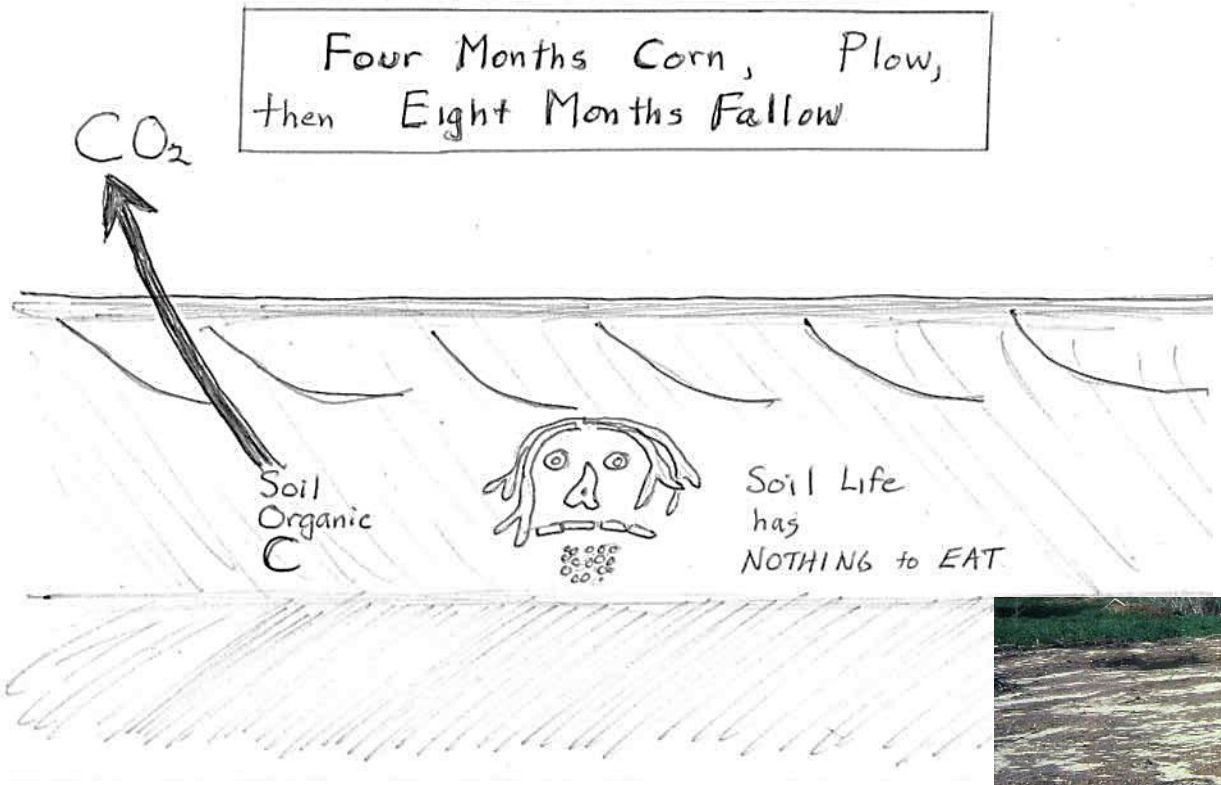
https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/mgnt/

Research Outcomes: Overview

- Validates NRCS Principles → *cover soil, maintain living roots, minimize disturbance, and build biodiversity*.
- Diverse, balanced organic inputs work together → *use both low and high carbon to nitrogen (C:N) ratio materials to build long term soil health and fertility.*
- Cover crops + amendments work together → *grow cover crops and use compost or manure in moderation for best soil health outcomes*.
- Organic no-till is highly beneficial but challenging .

Based on a review of USDA funded organic research 2002-2014 (Organic Farming Research Foundation, www.ofrf.org).

How *not* to manage soil health



Living plant cover:

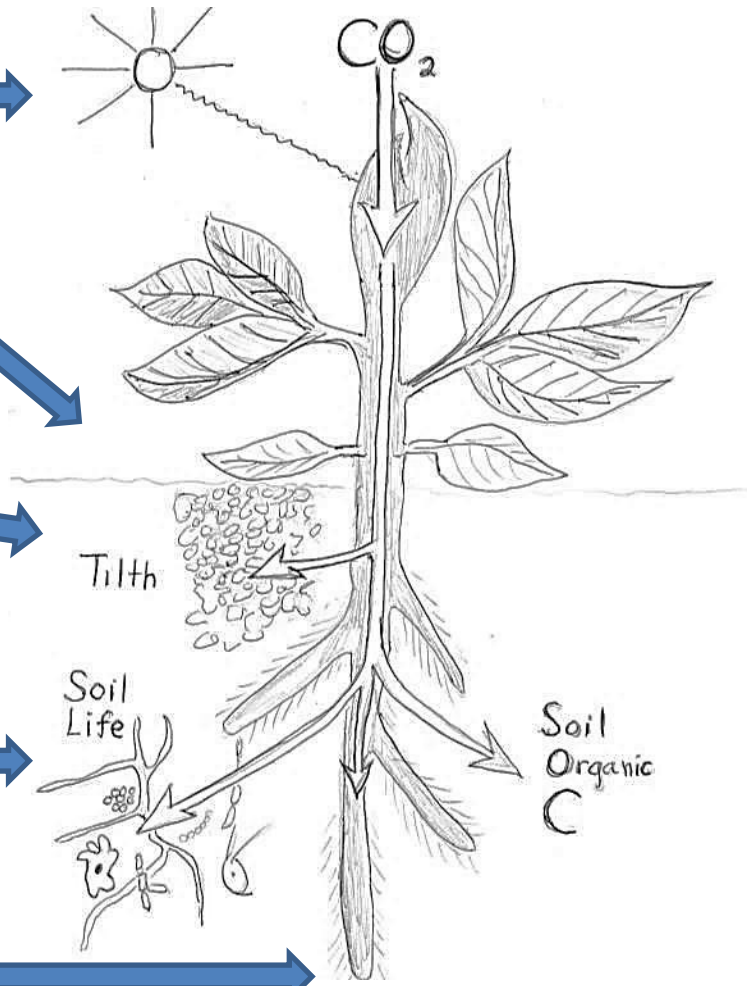
Keeps C flowing from atmosphere to soil

Protects the soil surface

Builds SOM and enhances soil structure

Feeds the soil life with root exudates, promotes beneficial organisms

Opens and deepens the soil profile



Energize the System through Diversity

Each species in a "cover crop cocktail" offers a different growth habit, root architecture, and suite of rhizosphere microbes.

Primary Soil Health Practices

- *Grow cover crops to maturity*
- *Design a tight crop rotation*
  - *Minimize bare fallow periods*
- *Diversify the crop rotation*
- *Include a perennial sod break in the crop rotation*
- *Limit soil disturbance*
  - *Reduce tillage if practical*
  - *Reduce soluble nutrient and pesticide inputs*

A cover crop of triticale and Austrian winter pea

Complementary Inputs and Practices

Purposes:	Practices and materials:
• Microbial inoculant	*Use good, finished compost* Commercial inoculants
• Protect soil, enhance habitat for soil life	Mulching Biochar and other soil conditioners
• Address nutrient and pH imbalances	Organic fertilizers, lime and other natural minerals
• Replenish SOM and nutrients consumed in production	Manure, compost, and other organic materials

More is not always better!

Soil Health Challenges

Degraded soil due to past mismanagement

Weeds!

Nutrient deficiency –
Nitrogen (upper)
Boron (lower)

Challenge #1: *How to assess soil health*

Scientists estimate soil health by measuring:

- *Total soil organic matter (SOM) or organic C,*
- *Active organic C,*
- *Total & active organic N,*
- *Total & active microbial biomass,*
- *Soil respiration.*

Scientists also conduct soil food web analyses:

- *Bacteria:fungi ratio,*
- *Nematode community,*
- *Indicator species, such as mycorrhizal fungi,*
- *Biodiversity measures,*
- *Indicator soil microbial enzymes.*

Limitations of lab analyses

- Random variability (e.g., total SOM)
- Interpretation (e.g. soil respiration, food web analysis)
- Site-specific nature of soil life & soil health properties
- Practical, reliable, affordable field methods
- Each measurement is just one dimension

Soil health is a multidimensional quality and cannot be captured with a single measurement.

Do your own Soil Health Assessments

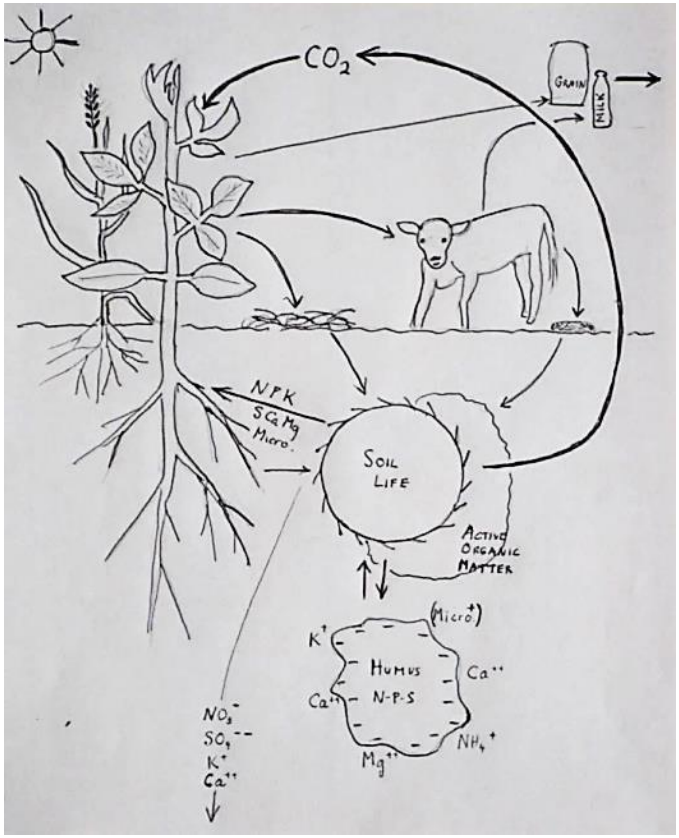
For each field monitor:

- *Soil tilth, color, rain infiltration, earthworms.*
- *Crop yield, quality, resilience to stress.*
- *Nutrient, SOM, and pH trends on soil tests.*

Soil health test kits can be helpful, though laborious.

Healthy soil makes healthy crops

Challenge #2: *Co-managing Soil Health and Plant Nutrition*



Nutrient cycles in agriculture can be leaky

- Soil health means enough plant nutrients, but not surplus.
- High soluble N can burn up SOM and leach to groundwater.
- Optimum N for crop yield may exceed optimum for SOM, soil health, and environment
- Using manure or compost for N can build up excess P.
- Tillage accelerates nutrient release – and loss of SOM.

Nutrient Management Example: Broccoli

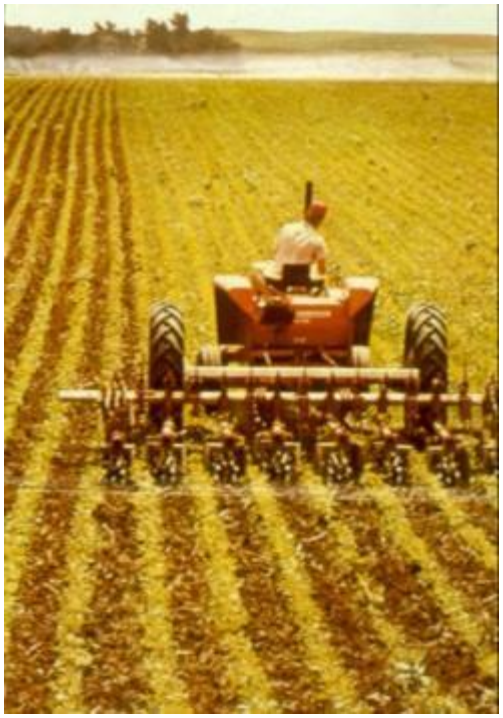
In California, organic broccoli required 220 lb N/ac for optimum yield, and:

- Leached ~180 lb N/ac
- Emitted 17-42 lb/ac N_2O, a powerful greenhouse gas
- Leached another 100 lb N/ac when broccoli residues were tilled in.

(U. California, Santa Cruz)

At Virginia Tech, broccoli required150 lb N/ac in addition to cover crop for maximum yield. Providing it with manure, poultry litter or compost would build up soil P, and may leach some N.

Challenge #3: *Co-managing weeds and soil health – the organic farmers' dilemma*



Cultivation takes out the weeds, but soil health may suffer.

- Tillage burns up SOM.
- Intensive tillage can reverse the benefits of a good crop rotation with cover crops.
- Organic no-till with cover crops builds SOM and soil health, but yield tradeoffs related to weed pressures often occur.

Challenge #4: *Today's crop varieties are not designed for soil-enhancing organic systems*

"Cultivars are most productive under the conditions for which they were bred ... [C]ultivars bred under conventional management – aided by synthetic fertilizer, herbicides and pesticides – will likely not be as productive under organic management."

Hultengren, R., M. Glos, and M. Mazourek, 2016. *Breeding Research and Education Needs Assessment for Organic Vegetable Growers in the Northeast*. Organic Seed Alliance, http://www.seedalliance.org/

Advantages and Challenges of Organic Systems

- Less chemical disturbance – no synthetic agrochemicals.
- Less soluble nutrient sources can reduce losses.
- No herbicides means greater flexibility in designing tight, diverse, crop rotations.
- Greater reliance on physical disturbance (tillage and cultivation) for weed control.
- Manure and compost, can add too much P relative to N and K.
- Timing of N release from organic sources is difficult to match with crop needs.

Advantages and Challenges in the Southern Region

- Long growing seasons and mild winters facilitate:
  - Year-round living cover
  - Crop rotation
  - High biomass cover crops
- Less severe yield tradeoffs with reduced tillage
  - On sandy soils, no-till can *improve* N synchrony and crop yields.
- Highly weathered "red clay" soils (Ultisols):
  - Nutrients leached from topsoil
  - Acidic, low fertility
- Hot, rainy climate accelerates SOM oxidation
- Intense weed pressure
- *Less organic soil health research to date in South than in other regions.*

Research Findings: Crop Rotation

"Short duration rotations with only corn and soybean production are detrimental to soil health … inclusion of a perennial like alfalfa in organic crop rotations is critical for weed control and soil maintenance."

Sheaffer, C. C., P. Nickel, D. L. Wyse, and D. L. Allan. 2007. *Integrated Weed and Soil Management Options for Organic Cropping Systems in Minnesota.* Final report for ORG project 2002-03806. CRIS Abstracts.*

Some Organic Crop Rotation Strategies

- Three-year: Corn-Soy-Winter Cereal/Red Clover
- Four-year: Corn-Soy-Winter Cereal/Alfalfa-Alfalfa
- Late winter frost-seeding clover into cereal grain
- Cereal grain as rotation crop for vegetables
  - Malting barley and other specialty cereal grains as soil-restoring crops.

After several years vegetables, hull-less oats + red clover were planted. Clover was grown for one year after oats harvest.

Perennial Sod Phase in Rotation

Rotating annual cropland into perennial grass-legume sod for two or more years can:

- Increase microbial biomass and diversity.
- Increase active and total SOM and organic N.
- Restore overall soil health
- Reduce weed pressure.
- Improve yields in following grain or vegetable crops.
- Meet the N requirement of a following corn crop (alfalfa or red clover plowdown).

Based on research findings in Illinois, Iowa, Maryland, Michigan, Minnesota, New York, Ohio, and Pennsylvania.

Research Findings: Cover Crops

- Multiple studies have confirmed the many soil benefits of cover crops.
- Fine roots comprise 70% of total root biomass in crimson clover, vetch, and field pea, and, upon cover crop termination:
  - Support microbial growth,
  - Form active SOM, and
  - Rapidly release plant-available N.
- Mowing cover crops enhanced these benefits over disking or herbicide.

(North Carolina State U)

Crimson clover

Legume Cover Crops and Organic Nutrient Management

- Legumes replenish soil N without adding P or K.
- If non-legume is present but not dominant, it can enhance N fixation.
- Perennial legume (alfalfa, red clover) plowdown ahead of field corn can meet total corn N requirement *(Cornell, U Minnesota, U Maryland)*

➢ *Credit legume N when deciding how much organic N to use.*

➢ *Do field comparisons ± added N.*

Austrian winter pea, a strong N fixer, with triticale at Virginia Tech in Blacksburg.

Combine legume and grass (e.g., rye, millet)

- All legume can leach N at plowdown.
- All cereal grain or grass can tie up N.
- Balanced mix (30 – 50% legume) optimizes biomass, N, soil health.
- Where soil soluble N is high, non-legume scavenges N.
- Where soil N is low, legume fixes N.

➢ *Adjust seeding rates so grass does not smother legume.*

➢ *Terminate at full bloom for greatest benefit.*

➢ *Mow tall grass component to release low-growing legumes (clovers, etc).*

Cereal rye and hairy vetch at optimum maturity (flowering)

Tillage Radish, the Nutrient Scavenger

Tillage radish, a cover crop cultivar of daikon radish, has formed dense canopy and sent roots 5 feet down.

- Mops up soluble N from top 5 feet of soil profile, can hold well over 100 lb N/ac.
- Retrieves P and K.
- Nutrients rapidly released in spring, plant-available P can increase, N may leach.
- Enhanced deep rooting in following corn or soybean: radish > rye > no cover.

Gruver et al., 2016. http://articles.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farming-systems.

What about those Cover Crop Cocktails?

Beginner's luck: a nicely balanced mix of oats, barley, mustard, and field pea in my garden.

- 3 to 15 species – legume, grass, crucifer, phacelia, buckwheat, etc.
  - for multiple "stacked" benefits.
- Promoted by NRCS.
- Research gives mixed results:
  - One crop (rye, canola) may dominate, depending on climate and soil N level.
  - Grass or buckwheat can smother legume – fine tune seeding rates.
  - Ongoing research to "farm-tune" cover crop mixes.

Research findings in Cornell and Penn State organic farming system trials

Research Findings: Compost & Manure

- Compost enhances:
  - Quantity and diversity of soil life
  - Active and total organic C and N
  - Tilth, porosity, and overall soil health
- More is not always better:
  - Maximum SOM and microbial biomass at rate recommended for crop nutrition (*U. Missouri*)
  - Corn yield plateau at *half* the recommended rate (*Cornell)*
  - Higher rates can stimulate weed growth *(Cornell)* and cause P and N excesses.

A good quality finished compost at a permitted composting facility.

Manure, Compost, and C:N Ratio

- SOM benefits of composted manure > uncomposted solid manure > slurry manure (very low C:N; half of N is ammonium) *(several studies).*
- Compared to poultry litter compost (low C:N), use of an on-farm mixed compost (higher C:N) led to:
  - Higher total soil organic C and N
  - Higher N mineralization potential
  - Better infiltration, lower bulk density *(Washington State U)*
- Poultry litter compost can enhance SOM and N mineralization potential over conventional systems, but can lead to excess P *(several studies).*

Budgeting Compost and Manure Nutrients

NPK levels in manure and compost can vary several-fold *(many studies).*

- *Get nutrient analysis for manure and compost.*
- *Adjust use rates according to soil test P levels:*
  - *On low-P soil, use at rates to meet N or K needs and build P.*
  - *If soil P is high or optimum, use compost to replenish P, and legumes to supplement N*
  - *For very high / surplus soil P, use compost sparingly as inoculant.*

Cover crops, organic amendments, and reduced till are additive and complementary

- Conifer-based compost (high C:N) and rapeseed (crucifer) green manure (low C:N) both enhanced soil microbial activity in organic potato *(U. Maine).*
  - Compost improved yields.
  - Green manure reduced potato diseases.
- Cover crops and manure compost improved soil health over either alone *(several studies*).
- Cover crop, compost, and reduced till (roll-crimped cover) in vegetables in IA and FL *(Iowa State U).*
  - Cover crop + compost enhanced SOM and organic N.
  - No-till further improved N retention and soil structure.

Several ways to reduce tillage organically

- *Interseed or frost-seed cover crops into standing grain or vegetable crop.*
- *Shallow till (rotary harrow)*
- *Strip till or ridge till*
- *Rotary spader – reduces compaction compared to plow-disk, can improve yields (Washington State)*
- Rotational no-till (rolled covers) can work well in warmer climates.

Organic summer squash planted no-till into rolled rye + vetch at VA Tech gave high yields. Organic no-till vegetables have also yielded well in FL and HI, while yields were somewhat reduced in IA.

Small scale organic no-till

Winter-killed pearl millet was raked off, compost spread, onion sets planted, residues replaced → good yield, no weeds!

- Weed mat over rolled winter cover for 2 weeks controlled weeds & regrowth for 8 weeks, sufficient for maximum tomato yield *(U. Maryland)*.
- Solarizing mowed millet-cowpea cover (clear plastic) for 2 days ensured termination. No-till fall broccoli gave very high yields and no response to added N *(A. Flaccavento, Abingdon, VA)*.

Research Findings: Tight N Cycling

Three types of organic tomato fields:

- N deficient – low soil N, low yield
- N saturated – high soil N, high yield and high leaching risk
- Tight N cycling – low soil N, high yield, minimal leaching risk

Rhizosphere organisms and plant enzymes promote efficient N mineralization and uptake in mature organic systems with soils amended with diverse, low- and high-C:N materials including cover crops.

(U. California at Davis)

Vigorous tomatoes grown on low-N compost in my home garden. Tight N cycling or more beginners luck?

A climate mitigation tip for organic farmers



Several studies have documented brief intense bursts of nitrous oxide (N_2O) emissions from organic fields. High levels of soil moisture, soluble N, and active organic C can lead to N_2O bursts.

- *Use diverse C-N balanced inputs to minimize this risk*

Maintaining soil health in vegetable crops

- Vegetable crops are low residue heavy feeders, and require cultivation for weed control
- *Cover crops are essential*
- *Use tight crop rotations*
- *Explore specialty grains as a soil-restoring, income earning rotation crop; overseed grain with clover.*
- *Reduce tillage if practical.*
- *Use in-row drip fertigation for precise placement and nutrient efficiency.*

Potato covers the ground well, but requires a lot of N and leaves scant residue after a soil-disturbing harvest.

Maintaining soil health in perennial fruit

- Moderate NPK requirements.
- Long term, minimum till.
- Soil health best under living cover or organic mulch, moderate in weed mat, worst in tilled or herbicide fallow.
- ➢ *Maintain living cover in alleys and under mature trees.*
- ➢ *Lay weed mat in two strips meeting in row to allow compost applications.*
- ➢ *Watch nutrient inputs and dynamics with applied organic mulches.*

Paul and Young-suk Estabrook's Virginia Gold Asian pear orchard in living grass sod.

Research Findings: Soil-friendly weed management

"*Crop rotation is probably the most important integrated weed management tool and should be the cornerstone of any weed management plan*"

- Hooks, C., A. Leslie, and G. Chen. 2016. *Managing weeds in vegetables organically*. University of Maryland Cooperative Extension, 18 pp.

Cover cropping for weed suppression

Clockwise from top left: radish (~40 DAP), oat, buckwheat (14 DAP), cowpea (37 DAP)

- *Use the best crops for the season and soil conditions.*
- *Use cover crops that emerge and grow rapidly, forming a dense canopy (examples at left).*
- *Include one or two such crops in mixes.*
- *For winter covers, include a species that will cover the ground quickly in fall, then winterkill.*

Cover cropping for weed suppression

- *Mix legume with cereal grains.*
- *Mix species with complementary architecture (example at right).*
- Leaving frost-killed cover crop residues on the surface over winter protects soil and allows ground beetles to consume weed seed *(multiple studies*) and improved bean yields over fall tillage in IL, MI, and NY *(Cornell)*.
- *Leave frost-killed cover crops undisturbed over winter.*

Summer mix of cowpea, buckwheat, pearl millet, and sorghum-sudangrass chokes out most weeds.

Nutrient management is also weed management

- Weed growth increased with application rates of high-analysis compost (4-5-2) well beyond nutrient-saturated rates for corn and kale. *(Cornell U*)
- Red clover plowdown can promote weeds (*Michigan State U)*

➢ *Avoid surplus NPK to limit weed competition with crops.*

- High carbon amendments (sawdust, straw) to tie up soil soluble N can give soybean a strong edge over weeds (*Ohio State U*).
- Organic no till soybean did well in rolled rye in IL, MO, NC.

➢ *Maintain low soil soluble N to give soybean and other strong N fixers a competitive edge over weeds.*

Research Findings: Plant breeding

N efficient and N fixing corn

- Traits from Mexican land races transferred into Corn Belt lines.
- Fix up to 50% of N requirement.
- Complex rhizosphere microbial dynamics.
- Competitive yields on soil low in soluble N.
- Superior protein content and quality.
- Can enhance soil and water quality in all corn production.

Walter Goldstein, Mandaamin Institute,

'Kentucky Rainbow' dent corn in Common Wealth Seeds variety trial in VA

Breeding crops for weed competitiveness

Vigorous winter squash lines selected by VABF member Edmund Frost (at left in photo) for disease resistance and fruit quality will also outcompete weeds. 'Danvers' carrot (right) has large tops and competes with weeds, but is disease prone. Carrot Improvement for Organic Ag (Purdue U) is developing large-top, weed-competitive, disease resistant cultivars.

Choosing crop cultivars for soil health

- *Select cultivars bred* in *and* for *organic systems – they will be better adapted to lower input practices and need less supplemental NPK.*
- *Select cultivars with vigorous aboveground and belowground (root) growth – they will add more organic matter and protect the soil better, as well as outcompeting weeds.*
- *Do side-by-side trials to see what varieties do best on your farm.*
- *Save and select seed to develop your own land races.*

Research Findings – Soil food web

- Scientists are just beginning to decode the “black box” of soil life.
- Each plant species releases its own “flavors” of root exudates and chemical signals.
- Each plant species has its own suite of micro-symbionts.
- Soil food web tests marketed to farmers can yield interesting data, but are expensive and hard to interpret.
- Commercial soil inoculants (e.g. mycorrhizal fungi) and soil conditioners (e.g. biochar) may be helpful, or harmlessly ineffective, depending on what is already in your soil.

➢ *Test these products in side by side trials with / without.*

Questions?

Watch for complete reports on soil health research later this year on the Organic Farming Research Foundation web site, www.ofrf.org.

This work is funded through a grant from the Clarence Heller Foundation .

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