Organic Farming: Tillage, Chemical Abstinence and Soil Resource Protection

Recent research findings and practical implications

https://ofrf.org

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Can We Grow Food Without Disturbing the Soil?

When wooded land is cleared for annual crops or grazing, soil microbiomes change, and some carbon is lost.

Korey Erb

Perennial Systems that Simulate the Native Plant Community Minimize Disturbance

Doug Crabtree

Pear orchard - Paul Estabrook

Permaculture - David & Lee O'Neill

Grazing – Meadow Creek Dairy

Silvopasture- Elmwood Stock Farm

But Much of our Diet is Annual Based





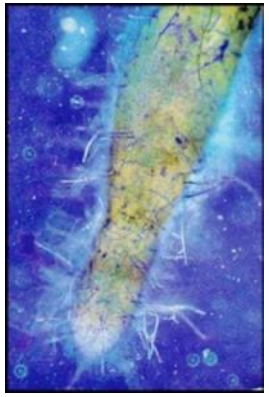


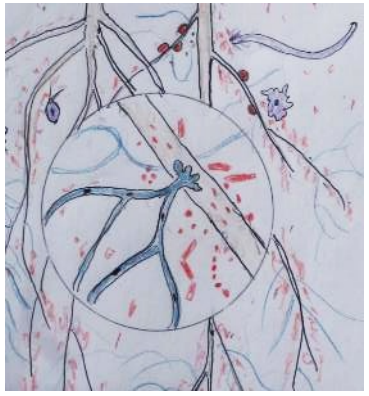


C. J. Isbell, Keenbell Farm

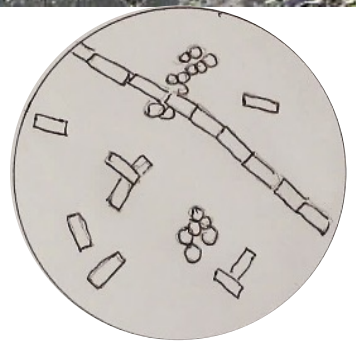
Healthy Forest Soils and Healthy Cropland Soils Differ

CO_2





Restoring Degraded Land with Best Soil Management



CO_2

How to Minimize Soil and Ecosystem Disturbance while Meeting our Needs for Food and Fiber

- "Half Earth" – E. O. Wilson
- 30 X 30 Initiative: Protect 30% of the world's land and oceans by 2030.
- Protect Indigenous rights, lands, lifeways; elevate Indigenous leadership.
- Expand perennial production – forest farming, orchards, pasture-based livestock, silvopasture, etc.
- Convert highly erodible and fragile land to perennial production with continuous soil coverage or natural areas.
- Organic / regenerative practices for annual crops – on least-erodible land.

How Does Annual Crop Production Disturb the Soil?

Tillage

Unplanted fallow

Moldboard plowing (left) "turns the house upside down" for soil life. Disking or rotary tillage can fragment fungal networks and promote wind erosion (center). Prolonged winter fallow can mean famine for soil life, even in no-till systems (right).

How Does Annual Crop Production Disturb the Soil?

Crop protection

Pixabay open-source photos

Concentrated nutrients

Soluble
N-P-K

Pesticides and herbicides (left) can hurt soil life. Concentrated nutrients (above) can alter soil microbial functions.

Minimizing Soil Disturbance:
Conservation Agriculture

CPS 329 No-till + 

CPS 340 Cover Crop → 

Cornell University

Roll-crimp and plant

USDA

No-till soy in rye

Washington State U

Strip tillage

USDA

Strip-tilled peanuts

No-till transplanter

No-till summer squash

Minimizing Soil Disturbance: **Conservation Agriculture**

CPS 328 – Conservation Crop Rotation:

Diversify rotation with:

- Cover crop mixes (M)
- Intercropping (IC)
- Relay planting (R)

E328E – Soil Health Crop Rotation:

- ≥ 4 different crops
- Maintain living root 90% of season
- High-residue crops and cover crops
- Minimal tillage

CPS 336 Soil Carbon Amendment:

- Compost, biochar, organic mulches
- Build SOC, habitat for soil organisms

Minimizing Soil Disturbance: **Conservation Agriculture**

Nutrient limitation

Disease

CPS 590 Nutrient Management

- E590A Improve nutrient use efficiency, reduce losses
- E590B Precision nutrient management

CPS 595 Pest Management Conservation System

- E595A Precision pesticide application
- E595B IPM through Prevention, Avoidance, Monitoring, and Suppression

Pests

Weeds

Minimizing Soil Disturbance: **Organic Agriculture**

National Organic Program (NOP) Standards on Chemical Disturbance

§ 205.202 Land requirements.

Any field … from which harvested crops are … labeled "organic," must:

(b) Have had no prohibited substances … for 3 years [prior to] harvest.

§ 205.206 Crop pest, weed, and disease management.

(e) When [cultural] practices … are insufficient … a biological or botanical substance … allowed for use in organic crop production may be applied.

§ 205.105 Allowed and prohibited substances …

[Organic products] … must be produced … without the use of:

(a) Synthetic substances … except as provided in [the National List]

Minimizing Soil Disturbance through **Organic Agriculture**

USDA Certified Organic producers can use NOP-allowed crop protection substances only if these other measures prove insufficient:

- Crop rotation, nutrient management.
- Sanitation
- Resistant cultivars.
- Physical barriers, repellents, lures, trap crops.
- Biological controls, natural enemies, beneficial habitat.
- Mowing, mulching, grazing, manual weeding, mechanical cultivation, flame.

NOP-approved disease controls include copper salts, peroxides, and microbial pathogen antagonists such as *Bacillus subtilis and B. pumilis.*

Minimizing Soil Disturbance through **Organic Agriculture**

NOP on Physical Disturbance and Nutrients

§ 205.203 Soil fertility and crop nutrient management:

(a) The producer must select and implement tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion.

(b) The producer must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials.

(c and d) The producer must manage [nutrient inputs] to maintain or improve soil organic matter (SOM) content and [avoid] contamination of crops, soil, or water.

An organic farmer in southwest Virginia tills a flail-mowed cover crop into the top 3-4 inches of soil.

Virginia Farm Story: Gearing-down the Rototiller

Rick Felker

Mattawoman Creek Farm crew sets vegetable starts into healthy, fertile soil with visible aggregates.

Rick and Janice Felker

Mattawoman Creek Farm, Cape Charles, VA

- 11 acres organic vegetables.

<u>Disturbance mitigation practices</u>:

- Rototiller operated at low PTO speed and 2.5 mph tractor speed to protect soil aggregates.
- Tight crop rotation – no bare fallow.
- High-biomass cover crops mowed and incorporated 3-4”.
- Permanent raised beds, controlled traffic.
- Organic fertilizers at moderate rates.
- All residues returned to the soil.

Minimizing Soil Disturbance through **Organic Agriculture**

NOP on Crop diversification

§ 205.205 Crop rotation practice standard.

The producer must implement a crop rotation including but not limited to sod, cover crops, green manure crops, and catch crops to:

(a) Maintain or improve soil organic matter content;

(b) Provide for pest management in annual and perennial crops;

(c) Manage deficient or excess plant nutrients; and

(d) Provide erosion control.

Organic crop rotations often include multiple plant families, keep the soil covered, and enhance soil biodiversity.

Virginia Farm Story: Strategic Rotation and Cover Cropping

A. Clovers sown into fall broccoli initiates the year-long green fallow.
B. Soybean and oats undersown into sweet corn

Pam Dawling, farmer and author

Twin Oaks Farm, Louisa, VA – central Piedmont

- 4 acres mixed vegetables for community of 100.

<u>Disturbance mitigation practices</u>:

- 10-year "tight" diversified crop rotation with:
  - One full year in green fallow (left A).
- Adaptive cover cropping:
  - Relay planting into vegetables (left B).
  - Irrigate cover crop seeding if soil is dry.
  - Fill short gaps with buckwheat, soy, or oats.
  - Contingency plan for crop failure – plant high-biomass cover – e.g., sorghum-sudangrass.

A Comparison of Soil Disturbance and Soil Health Practices in Three Agricultural Systems

Disturbances:	Best Organic Practices	Conservation Agriculture	Conventional Agriculture
Tillage intensity	Low to moderate	None or minimal	Low to high
Unplanted fallow	Minimal	Minimal	Often prolonged
Pesticides	Low*	Low to moderate	Moderate to high
Soluble nutrients	Low to moderate*	Moderate**	Moderate to high
Soil health practices:			
Soil cover, living root	Most of the year	Most of the year	Often inadequate
Crop diversification	Substantial	Substantial	Often limited
Organic amendments	Used regularly	Used often	No or limited use

** NOP-allowed materials only.* *** 4-Rs nutrient management.*

Virginia Farm Story: Crop-Livestock Conservation Agriculture

C. J. Isbell

Keenbell Farm, Rockville, VA (central Piedmont)

- 340 acres, grass fed beef, pork, poultry, eggs, specialty grains, popcorn, milling corn, and soybeans.

<u>Disturbance mitigation practices</u>:

- One-time herbicide to “reset” weedy new land; all other practices and inputs are organic.
- Winter and summer cover crop mixes no-till drilled and rotationally grazed.
- Grains for market once every 3 years in rotation.
- Precision nutrient application based on intensive soil testing, pastured poultry, and organic fertilizers.

A. Cattle grazing cover crop, moved daily. B. pastured poultry deliver nutrients where soil tests show need.

Reducing Tillage Intensity in Organic Systems

Low-impact tools for various purposes
and different scales of operation

Conservation Tillage Practices and Organic Systems

- **Soil Tillage Intensity Rating** (STIR) is a science-based estimate of the impact of various tillage and other field operations on soil life and soil health, used in the Revised Universal Soil Loss Equation (RUSLE2).
- **CPS 329 No Till**
  - No full-width tillage.
  - Total crop cycle STIR ≤ 20.
  - *Difficult to sustain throughout an organic annual crop rotation*.
- **CPS 345 Reduced Tillage**
  - Non-inversion tillage only.
  - Total crop cycle STIR ≤ 80.
  - *Many organic farmers reduce tillage to this level*.

An Example of a Conventional Tillage Regimen

Primary

Secondary

Cultivation for weed control

Operation	STIR
Moldboard plow, 8” depth	65
Tandem disk w/ rolling basket	41
Planter, double disk opener	2
Rod weeder	17
Cultivator, inter-row	15
Total for crop cycle	**140**

Impacts:

- Loss of SOM
- Degradation of aggregates
- Harm to fungi and larger organisms

Shallow Non-inversion Tillage: Power Harrow STIR = 21 *

- Vertically-oriented tines rotate in horizontal plane – avoids forming a tillage hardpan.
- Makes seedbed.
- Incorporates amendments and light residues.
- Takes out small weeds.
- Leaves most of the soil profile undisturbed.

**STIR ratings obtained from current RUSLE2 program.*

Power harrow tool works top 2-3 inches gently, leaving a crumbly seedbed.

Shallow, Non-inversion Tillage: High-speed Disk STIR = 41 (with rolling basket)

Justin Rich, Huntington, VT

- Working depth 2-4 inches.
- Tractor forward speed 7-12 mph.
- Incorporates cover crops, makes seedbed.
- Time and energy efficient.
- Primary tillage for many organic farmers.

"Vertical tillage"

- Coulters in line (zero angle) STIR = 9.
- Coulters + spiketooth harrow STIR = 19.

Deep Non-inversion Tillage for Small Scale: Broadfork

STIR ~ 4 *

- Deep tillage may be needed to:
  - Break subsurface hardpan
  - Manage larger weeds
- Other non-inversion tools that can relieve compaction:
  - Chisel plow (STIR = 53 for 7” depth with coulter).
  - Para-plow, subsoiler (STIR = 18).
  - Vertical tillage tools – coulter, followed by narrow shank to prepare seedbed (STIR = 19).

* Highest value listed for “manual cultivation.”

The broadfork is an excellent tool for root crop harvest and working raised beds in high tunnel and market gardens.

Kentucky Farm Story: Intensive Cropping, Gentle on Soil

Jesse Frost and Hannah Crabtree

Rough Draft Farmstead, Lawrenceburg, KY

- 1 acre vegetables, intensive multicropping.

<u>Disturbance mitigation practices</u>:

- Broadfork annually to loosen soil.
- Spent crops cut at ground level (not uprooted).
- Permanent beds, living plant cover in alleys.
- Intercropping and relay planting, e.g.:

<u>Spring</u> <u>Summer</u> <u>Fall</u>

Radish → Green onion

Summer squash → Napa cabbage

A. Interplanting lettuce and green onions. B. Lettuce and spinach nearly ready for harvest.

Moderate-impact Deep Tillage: Spading Machine
STIR = 31

Rotary or reciprocating spaders:

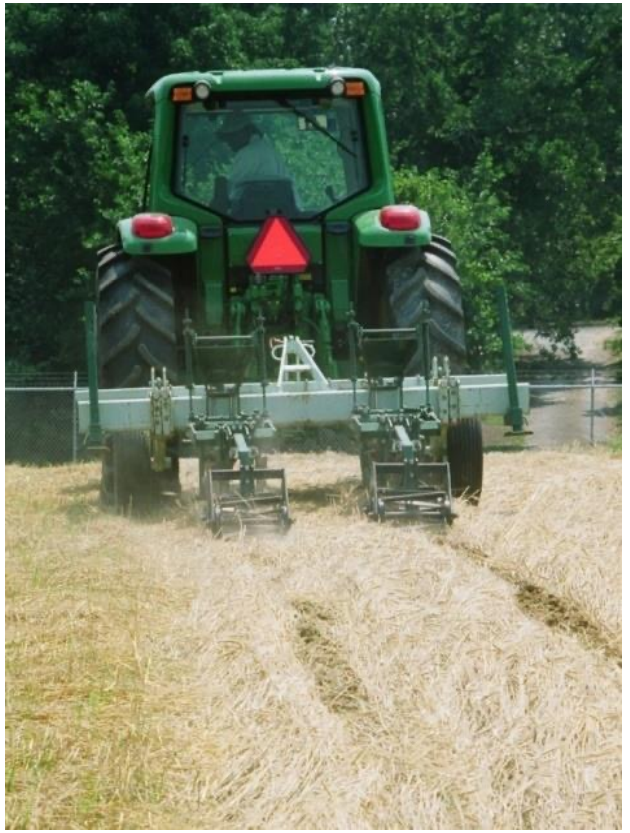
- Do not pulverize soil aggregates.
- Do not create tillage pan.
- Mix rather than inverting soil.
- Can incorporate cover crops or sod in one pass.
- In Washington State U. organic vegetable systems trials, the spader:
  - Reduced compaction at 5-12 inches.
  - Sometimes improved yields over plow-disk.

Washington State U. Extension

Tilling Part of the Field: Strip Tillage

STIR = 5 - 7

Washington State U



Two types of tractor-drawn strip tiller work a narrow strip for each crop row, leaving 70 – 80% of the soil surface undisturbed and covered with residues.

Rotational No-till in Organic Production

Organic no-till begins with a high-biomass, weed-free cover crop with a closed canopy (A), which is roller-crimped (B), and followed by no-till trans-planting or seeding the production crop (C). When all goes well, the cover crop residue suppresses weeds and supports a vigorous high-yielding crop such as this summer squash (D). Normally, some tillage is needed after harvest to plant the next cover crop; hence "rotational no-till" (E).

Organic No-till is Challenging and May Fail if:

Cover crop is thin.

Weed seed bank is large.

Perennial weeds are present.

Cover crop Is planted just after breaking sod.

Overmature cover crop self-seeds. Squash in barley + crimson clover (left, self seeded) vs rye + vetch (right).

Cooler soil under residue slows N mineralization or cover crop consumes N or moisture, causing yield loss.

When Organic Rotational No-till is Most Likely to Succeed

- High biomass weed-free cover crop.
- Warm rainy climate, e.g., southeastern US.
- Healthy soil, good tilth.
- Light textured (sandy) soils that warm up quickly.
- Strong N fixer planted into high-carbon residues (right).
- Farmer has equipment and experience for no-till.
- Tips:
  - Roll-crimp twice to ensure termination.
  - Adjust planter for high residue – coulter type, row cleaner, added weight on toolbar

USDA

Organic no-till soybean in roll-crimped rye.

New York Farm Story: Rotational No-till for Organic Grains

Klaas Martens and Mary Howell Martens

Martens Organic Farm, Penn Yan, NY

- 1,900 acres grains, forages, dry beans, and vegetables

Disturbance mitigation practices:

- No-till planting sequences as long as practical, e.g.:

Barley → sorghum-sudan forage → rye + peas → roll-crimp for no-till soybean → overseed cereal in fall.

- Strategic rotations to suppress weeds and diseases.

When tilling is needed:

- Rotary harrow or speed disk (2-3”) to work in residues.
- Subsoil then plant canola to break hardpan.
- European plow, partial inversion, 4-6” for heavy residues.

Rye and winter peas no-till drilled into sorghum-sudan stubble, which provides favorable microclimate for seedling establishment.

What does the Research Show?

Impacts on SOM and Soil Microbial Communities:

- Tillage
- Crop protection materials
- Fertilizers

Making Sense of Conflicting Results: Does One Tillage Pass Ruin Soil Health?

- Single studies can give wildly different answers to this vital question.
- Reviews of multiple studies can identify trends.
- Meta-analysis, a statistically rigorous compilation of dozens or hundreds of individual studies, can quantify overall trends and elucidate drivers of variation among outcomes.

Shallow sweep tillage kills weeds and leaves residues on the soil surface, but may oxidize near-surface SOM.
Will this soil remain healthy?

Research findings:
Tillage, SOM, and Soil Biology

Shallow tillage to incorporate a substantial cover crop residue feeds soil life and can sustain or build SOM.

- Conservation tillage (no or reduced till) increases microbial biomass, SOC, and soil organic N. [1]
- No-till increases microbial biomass and enzyme activity and reduces metabolic quotient ($qCO_{2,}$, ratio of respiration rate to microbial biomass). [2]
  - Higher microbial biomass with chisel plow (non-inversion) than moldboard plow (inversion).
- Shallow non-inversion tillage + organic practices can build SOM. [3,4]

[1] Chen et al., 2020 (meta-analysis); [2] Zuber and Villamil, 2016, (meta-analysis); [3] Sun et al., 2016; [4] Krauss et al., 2020.

Research findings:
Microbial Biomass in Three Tillage Systems[1]

Inversion 8-10”

Noninversion <6”

No tillage

	Reduced Till	No Till
Bacterial	+ 93% *	– 5%
Fungal	+ 92% *	+ 28% *
Total microbial	+ 99% *	– 4%

Why did no-till underperform in this global meta-analysis?

- Compaction, sealing, reduced porosity, restricted gas exchange.[1]

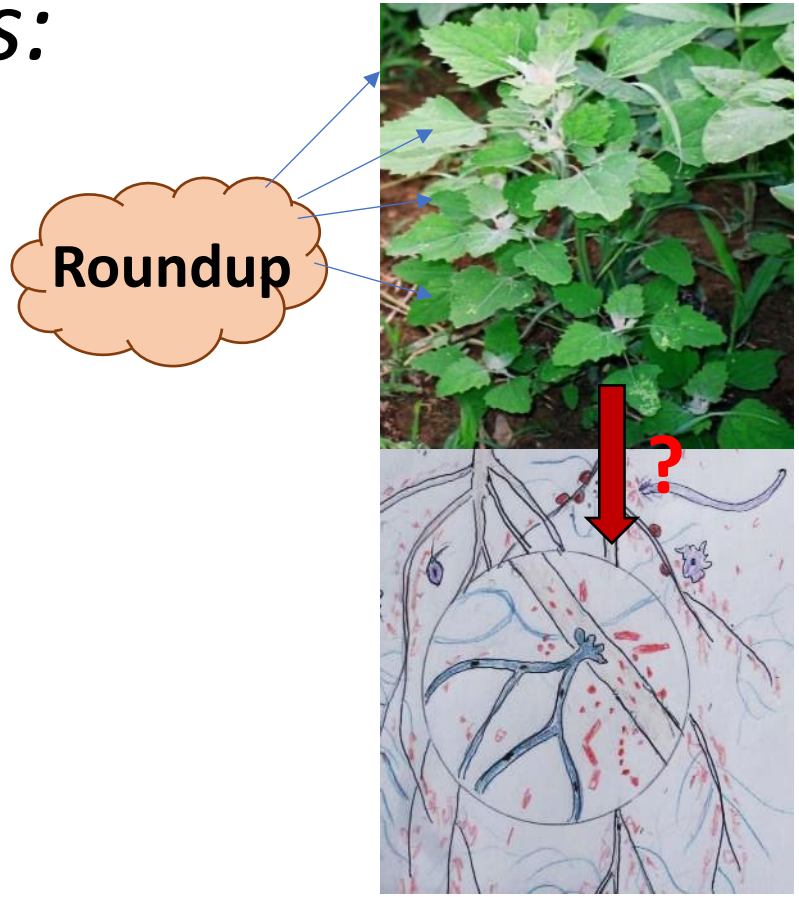
Possible additional factors:

- No or inadequate cover cropping?
- Greater dependence on herbicides?

[1] Morugán-Coronado et al., 2022 (meta-analysis) * *Statistically significant.*

Making Sense of Conflicting Results: The Case of Glyphosate

- High levels of *Fusarium* pathogens in wheat,[1] corn, and soybean[2] in fields treated with glyphosate.
- No effect on corn or soy root microbiomes or *Fusarium* 20 days after glyphosate application.[3]
- Reduced arbuscular mycorrhizal fungi (AMF) spore viability and root colonization.[4]
- Reduced earthworm activity and reproduction.[5]
- *Review article:* mixed results, neutral to moderately adverse impacts on soil organisms.[6]



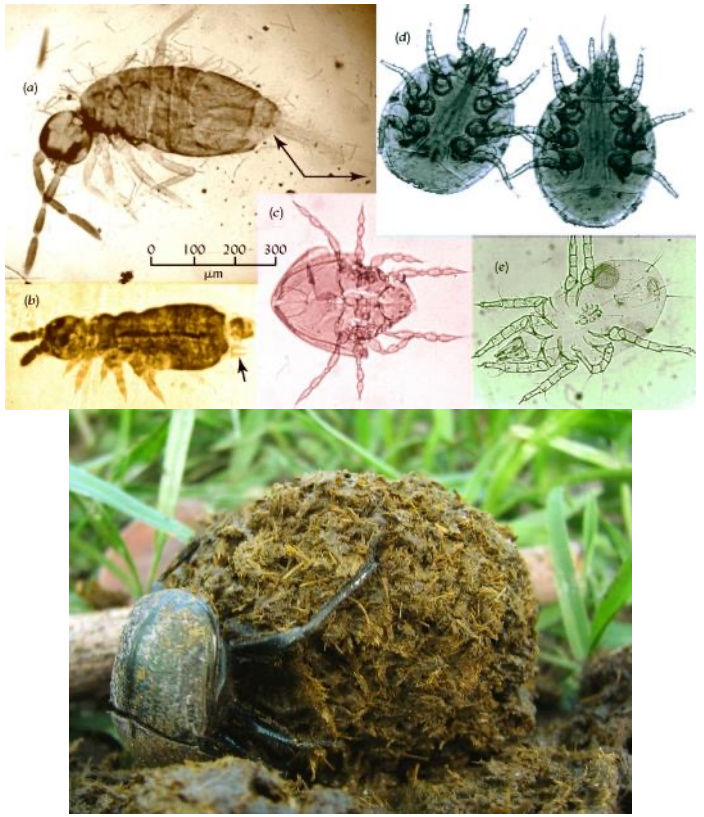
Does spraying cropland weeds with glyphosate harm soil health? More research is needed.

[1] Fernandez et al., 2009; [2] Kremer and Means, 2009; [3] Kepler et al., 2020; [4] Druille et al., 2013; [5] Gaupp-Berghausen et al., 2015; [6] Gunstone et al., 2021 (review).

Research Findings:
Pesticides and Soil Organisms

- Literature review[1] of pesticide impacts on earthworms, nematodes, and arthropods found:
  - ➢ All soil invertebrates affected by all pesticide types.
  - ➢ Negative impacts in 81% of lab and 53% of field assessments. Positive impacts rare (1.4%).
  - ➢ Toxicity in field: insecticides > fungicides > herbicides.
- Seed treatments alter rhizosphere microbiome and affect soil invertebrates. [2,3]
- Two herbicides used together may act synergistically, having much greater effect on soil microbes than either alone. [4,5]

[1] Gunstone et al., 2021; [2] Atwood et al., 2018; [3] Nettles et al., 2016; [4] Tejada, 2009; [5] Joly et al., 2012.



Springtails (top left), mites (top right), dung beetles (bottom) and other soil arthropods play key roles in soil health and fertility.

Research Findings:
Pesticides and Earthworms

Research into pesticide impacts on earthworms [1] indicates that:

- "*Pesticides disrupt enzymatic activities, increase individual mortality, decrease fecundity and growth, change … feeding rate, and decrease … community biomass and density.*"
- Organic systems had 18% higher populations and 46% more earthworm biomass than conventional.
- Synergistic impacts of two or more crop protection chemicals.
- Research needed to evaluate impacts in the field.

[1] Pelosi et al., 2014 (review).

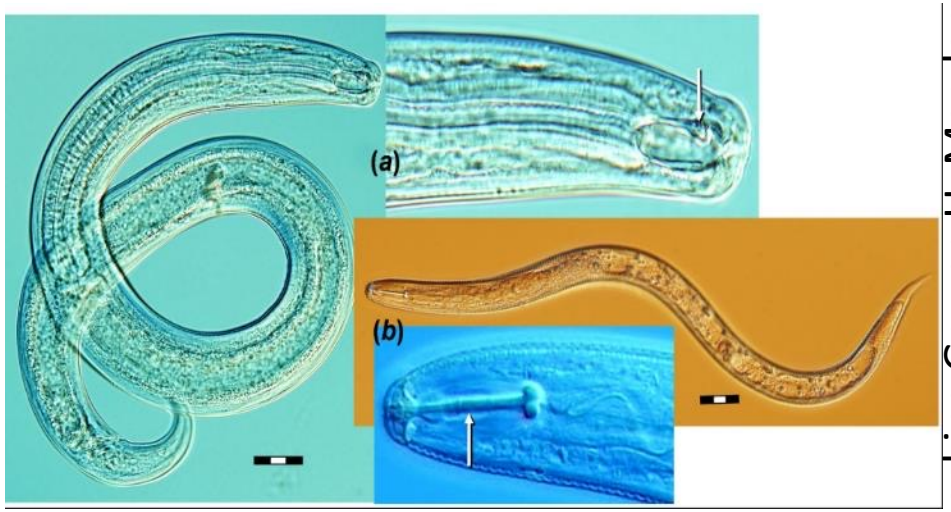
European nightcrawler and casts (top; photo credit Ray R. Weil, U. Maryland). Red wiggler in compost.

Research Findings:
Pesticides, Crop Rotation, and Soil Nematodes

Studies of soil nematode communities[1] found that:

- Chemical inputs and monoculture reduce abundance, diversity, and community structure.
- Nematicides are most harmful.
- Fertilizers and herbicides are least harmful.
- Crop rotation (3 years or more) reduces root-feeding (pest) nematodes by 47%.
- Cover crops enhance omnivore and predator nematodes by 80%.
- Organic fertilizers more than double bacterial- and fungal-feeding nematodes over soluble NPK.

[1] Puissant et al., 2021 (meta-analysis)



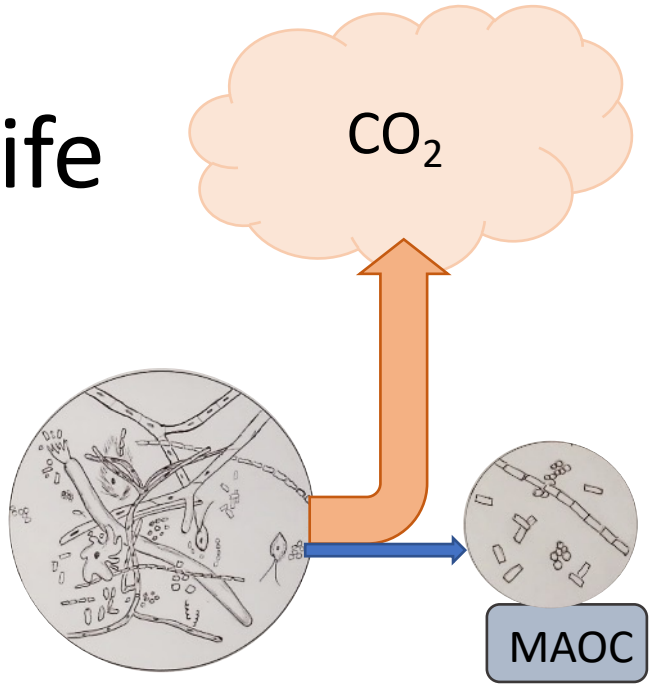
Lisa Stocking Gruver, U. Maryland

Predatory nematode and mouth parts (a); root-feeding nematode and mouth parts (b). Nematode community structure and diversity are key indicators of soil health.

Research Findings:
NOP-Allowed Pesticides and Soil Life

- Copper fungicides can increase soil microbial respiration and metabolic quotient (qCO_2) and reduce microbial biomass.[1]
- Azadirachtin (neem) adversely affected mung bean root microbiome to a similar degree as chemical pesticides.[2]
- An NOP-allowed, vinegar-based herbicide used three times during a season cut mycorrhizal density by half.[3]

[1] Merrington et al., 2002; [2] Singh et al., 2015; [3] Atthowe, 2010



Stressed microbiome consumes more organic C through respiration (higher qCO_2), leaving less for microbial growth and stable SOC.

Plastic Film Mulch: an NOP Allowed Synthetic

- NOP requires plastic film mulch removal at the end of the season.
- No biodegradable film mulches have met current NOP criteria for their use in organic production.
- Microplastic residues from film mulches added to soil at 89 lb/ac had no effect on soil microbiome or barley yield.[1]
- Residual plastic film at 135 to 425 lb/ac severely reduced microbial activity, SOC accrual, and cotton yields.[2]

[1] Greenfield et al., 2022; [2] Wen et al., 2022

Plastic mulches save a lot of weeding labor, but can they add to microplastic soil pollution?

Georgia Farm Story: Minimum Tillage with Tarping

A. Cover crops are terminated with solid landscape fabric, which is later replaced with fabric with planting holes.
B. Fabric keeps strawberry crop weed-free through harvest.

Bryan Hager

Crager-Hager Farm, Bremen, GA

- 1.5 acres vegetables and strawberries in field and high tunnels

<u>Disturbance mitigation practices</u>:

- Landscape fabric tarping – excludes light, air- and water-permeable (left).
- Cover crops mowed, tarped for one month.
- Outdoor beds tilled shallowly to work in cover crop residues and amendments
- Hoophouse beds broadforked annually, residues and amendments hoed in.

Research Findings:
Pesticides, Tillage, and Soil Life

- In central Europe (60 sites), pesticide residues impacted the soil microbiome more than tillage or other management variables.[1]
- In Estonia (78 sites), pesticides and soluble fertilizers reduced fungal biodiversity in agricultural soils while tillage did not.[2]
- Tillage practices have less impact on nematode community structure than either pesticides or organic versus soluble fertilizer.[3]
- Tillage and pesticide exposure may act synergistically in their adverse effects on earthworms.[4]

[1] Walder et al., 2022; [2] Vahter et al., 2022; [3] Puissant et al., 2021 (meta-analysis); [4] Pelosi et al., 2014 (review).

Research findings:
Organic versus Soluble Nutrient Inputs

VS

- Soils receiving organic fertilizers support more than twice the microbial biomass found in soils fertilized with soluble NPK.[1]
- Organic N sources build SOC, reduce N leaching 43%, and NH_3 volatilization 52% compared to soluble N.[2]
- Compared to soluble NPK, organic fertilizer (manure) enhanced bacterial diversity, SOC (+38%), carbon and nutrient cycling, and wheat yields (+13%), over a 7-year period.[3]
- Soluble NPK fertilizers favored fungal pathogens while organic fertilizers supported beneficial bacteria.[4]

[1] Morugán-Coronado et al., 2022 (meta-analysis); [2] Young et al., 2021 (meta-analyses); [3] Li et al., 2022; [4] Zhang et al., 2022a

Is Soluble N Toxic to Soil Life?
Not if C:N ratio is balanced!

- Substituting half of soluble NPK with organic sources enhanced microbial diversity, P cycling, and crop P nutrition.[1]
- Combined organic and soluble N built as much SOC as all-organic N, with N leaching and NH_3 volatilization rates intermediate between those for all-organic and all-soluble N.[2]
- In organic vegetable production, finished compost (C:N ~20) supported much higher SOC accrual and microbial activity than poultry litter (C:N ~ 7) at equivalent N rates.[3]

1 Zhang et al., 2022b; 2 Young et al., 2022, (meta-analyses); 3 Bhowmik et al., 2016, 2017.

Protecting the Soil Resource in Organic Crop Production

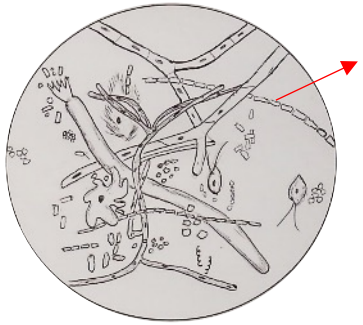
- Practical guidelines

Know Why you are Disturbing the Soil

North ← Virginia → South

Cold

Appalachia Piedmont Tidewater Hot



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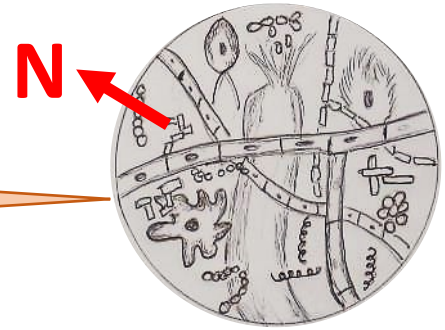
Nutrient mineralization



N

Seedbed preparation, incorporate residues and amendments

Manage weeds, pests, and diseases

Tips for Minimizing and Managing Soil Disturbance in Organic Production

- Maximize year-round soil coverage and living roots.
- Diversify the cropping system.
- Use integrated weed management to reduce need for cultivation.
- Till with care and only when needed:
  - Shallow, non-inversion tillage.
  - Low-intensity implements.
  - Avoid inversion-plowing deeper than 6 inches.
- Use concentrated nutrient sources (e.g., poultry litter) sparingly.
- Use NOP-allowed pesticides only when cultural and biological controls fail.


Questions?
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