Organic Practices for Climate Mitigation, Adaptation, and Carbon Sequestration

Research-based Practical Guidance for Organic and Transitioning Farmers

Mark Schonbeck
Organic Farming Research Foundation
Produced with funding from the Clarence E. Heller Charitable Foundation

Climate Change in the News

*International Panel on Climate Change, 2018:*
- 2.0°C warming too risky
- Net zero emissions by 2050 to achieve ≤1.5°C

*Fourth US National Climate Assessment, 2018:*
- Major risks to public health, economy, society
- Mitigation and adaptation urgently needed

*Green New Deal House Resolution 109, Feb 7, 2019:*
- National mobilization to net zero by 2050
- Community-based resilience endeavors
- Afforestation, soil carbon storage, soil health
Climate Change and Agriculture

Impacts:
• Increased drought and heat → reduced productivity
• Extreme precipitation events → soil erosion, water degradation
• Heat stress → livestock and human health risks
• Damage to rural infrastructure + existing poverty → limited capacity to adapt

*2018 National Climate Assessment, pp 88-89*

![Corn showing water deficit stress during 1995 drought in Kutztown, PA.](image)

Climate Change and Organic Farming

**Farmer Research Priorities**

Soil health – 74%
Climate change – 34%
• Drought – Western region
• Excessive rain – Northeast, South
• Chill hours – fruit and nut crops
• Adapted crops and varieties
• New weeds and pests
• Soil carbon sequestration

*Available at [http://ofrf.org/](http://ofrf.org/)*
Can Organic Practices Help Farmers and Ranchers Prepare for Climate Disruption?

Soil Health and Resilience to Weather Extremes

Organic Farming and Resilience

Over a 35 year period, organic farming systems:

- Increased soil moisture uptake by 15-20%
- Reduced runoff
- Created stable soil aggregates
- Improved crop nutrition
- Built soil organic matter (SOM) by 6 tons/ac

In the Rodale Farming Systems Trials, organically grown corn (left) withstood the 1995 drought and yielded 31% more than conventional corn (right).
Soil Health and Climate Resilience

Rain soaks in.
Healthy soil holds ample moisture.
Abundant soil life partners with plants.
Healthy soil drains well, stays aerated.

Guidance for Building Resilient Soils

National Organic Program (NOP) Soil Fertility Standard:
• Tillage practices must protect soil health and minimize erosion.
• Manage nutrients with rotation, cover crops, organic amendments.

NOP Crop Rotation Standard:
• Include sod, cover, and catch crops.
• Build SOM
• Control erosion.
• Optimize crop nutrients.

Five Principles
• Keep soil covered.
• Maintain living roots.
• Diversify crops.
• Minimize disturbance.
• Integrate livestock.

NRCS (first four); Gabe Brown, rancher (fifth).
The Living Plant is the Farmer’s #1 Tool for Building Resilient Soils

Photosynthesis creates organic matter.

Foliage protects soil surface.

Living roots:
- Build SOM
- Maintain tilth
- Feed soil organisms
- Open and deepen soil profile

How Does Agriculture Affect Climate?

Greenhouse Gas (GHG) Emissions
- Carbon dioxide (CO₂)
- Nitrous oxide (N₂O)
- Methane (CH₄)

Carbon Cycle: Soil and Plant Cover
Greenhouse Gases in Agriculture

<table>
<thead>
<tr>
<th>Gas</th>
<th>$\text{CO}_2\text{eq}$</th>
<th>$\text{CO}_2\text{-Ceq}$</th>
<th>Sources in Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2$</td>
<td>1</td>
<td>1</td>
<td>Fossil fuel – field operations&lt;br&gt;Inputs – embodied energy&lt;br&gt;Lime, urea, field burning&lt;br&gt;SOC losses&lt;br&gt;Forest clearing, breaking sod</td>
</tr>
<tr>
<td>$\text{CH}_4$</td>
<td>21</td>
<td>7.6 ($\text{CH}_4\cdot\text{C}$)</td>
<td>Livestock enteric methane&lt;br&gt;Manure storage&lt;br&gt;Paddy rice cultivation</td>
</tr>
<tr>
<td>$\text{N}_2\text{O}$</td>
<td>310</td>
<td>133 ($\text{N}_2\text{O}\cdot\text{N}$)</td>
<td>N-fertilized soil&lt;br&gt;Manure (in pasture &amp; storage)</td>
</tr>
</tbody>
</table>

**Direct Agricultural GHG Emissions**

- **US, 2016 (EPA)**
  - Soil $\text{N}_2\text{O}$
  - Enteric $\text{CH}_4$
  - Manure storage
  - $\text{CH}_4 + \text{N}_2\text{O}$
  - Rice $\text{CH}_4$
  - Other *

  8.6% of total US GHG

- **Global, 2010 (IPCC)**
  - Soil $\text{N}_2\text{O}$
  - Enteric $\text{CH}_4$
  - Manure storage
  - $\text{CH}_4 + \text{N}_2\text{O}$
  - Rice $\text{CH}_4$
  - Other *

  12% of total global GHG

* Field/residue burning and other sources
Adding in the CO₂

Add direct & embodied CO₂ (US)
- CO₂ inputs + field ops
- N₂O, all direct sources
- CH₄, all direct sources

~10% of total US GHG

Add soil C losses (global)
- SOC losses, erosion
- N₂O, all direct sources
- SOC losses, in situ
- CH₄, all direct sources

~24% of total global GHG

Soil and the Global Carbon Cycle

Soil: 3,000 organic 940 inorganic

Vegetation 620

Fossil Fuels 5,000

Atmosphere 790

Oceans 38,000

Based on Weil & Brady, 2017. The Nature and Properties of Soils

C pools: billions of tons. Flows: billions of tons/yr.
The Carbon Cost of Clearing Land

30 – 50% SOC losses in 50 yrs.

Can Agriculture Become Part of the Climate Solution?

- Improved soil health practices for carbon sequestration
- Organic farming systems
- Rotational grazing
- Mitigating $N_2O$ and $CH_4$
Can “Carbon Farming” Offset GHG by Converting CO\textsubscript{2} into Soil Organic C?

- **Not much** – focus on mitigating N\textsubscript{2}O and CH\textsubscript{4}.
  - Poulson et al., 2011.
- **We can put a significant dent in it.**
  - Chambers et al., 2016.
- **Agriculture can become climate-neutral.**
  - Lal, 2015; Teague et al., 2016 (4 per 1,000 Initiative)
- **Organic agriculture can mop up all human-caused GHG emissions.**
  - Rodale Institute, 2014.

The Living Plant is Humanity’s Most Practical Means to Sequester Carbon

- Photosynthesis removes atmospheric carbon dioxide (CO\textsubscript{2}).
- Roots and root exudates build soil organic carbon (SOC).
- Deep roots build stable SOC below tillage depths.
Management of SOM to enhance soil quality involves balancing two ecological processes: **mineralization** of carbon (C) and nitrogen (N) in SOM for short term crop uptake, and **sequestering** C and N in SOM for long term maintenance of soil quality.

Delate et al., 2015.

**SOC/Crop Production Tradeoff?**

- **CO₂**
- **N**
- Stable SOC

**Best Organic Practices Build SOC and Soil Fertility**

Microbial respiration and SOC increase together in organic farming systems:
- Six long term farming systems trials (US)
- 56 comparisons, organic vs conventional (global)
  - SOC up 19%
  - Microbial activity up 74%

Stabilization favored by:
- Finished compost
- Reduced or no till

Mineralization favored by:
- Cover crops, especially succulent green manures
- Raw manure, poultry litter
- Soluble N fertilizers
- Tillage
Soil Carbon Sequestration 101:
NRCS’s Four Principles of Soil Health

- Keep soil covered.
- Diversify the cropping system.
- Maintain living roots.
- Minimize disturbance.

What Will it Take?

Annual SOC sequestration on the world’s 12.2 billion acres of agricultural lands needed to:

- Offset direct agricultural GHG: 325 lb./ac
- Meet 4 per thousand goal, make agriculture climate-neutral: 660 lb./ac
- Offset all human GHG emissions: 2,470 lb./ac

Global cropland 3.51 billion acres
Global grazing land 8.65 billion acres
C Sequestration by Different Conservation Practices

Continuous no-till, cash crop residues only: 510 lb./ac-yr. Not stable

Cover crop: 135 – 195 Lb./ac-yr.

Cover crop + no-till, roll-crimping and planting in one pass: 440 – 800 lb./ac-yr.

C Sequestered in Diversified Rotation

Diversifying the crop rotation: 180 – 470 lb./ac. More stable
C Sequestered by Improved Grazing Management

Prescribed grazing
150 – 400 lb./ac-yr.

Management-intensive rotational grazing (MIG): ≥ 2000 lb./ac-yr.
*Highly stable*

C Sequestered by Perennial Plantings

Herbaceous perennial conservation buffers, field border, filter strip, etc.:
375 – 800 lb./ac-yr.

Agroforestry practices, SOC + aboveground biomass C:
2,400 – 3,700 lb./ac-yr.
(semiarid – humid regions)
Agroforestry: Rural and Urban

Silvopasture (left) and converting disused urban land to diversified home or community food gardens (right) can sequester 1 – 2 tons of carbon as SOC annually.

How Plant Roots Build Stable SOC

Soil biological activity is concentrated near surface; SOC turns over quickly.

At least half of SOC occurs deeper than 12 inches, where it has greater stability.

Annual crops root to 3 – 6 ft.; perennials 5 – 10 ft. or deeper.
SOC Saturation

1. Depleted cropland → permanent pasture
2. Cropland → MIG pasture
3. Continuous no-till crops
4. Organic cropping system
5. Diversify rotation (not org.)

Steady state SOC:
- Cropland ~55% of native
- Best soil health mgmt. →85%
- Future innovation→100%?

---

We Know Enough to Act Now

“Agriculture and natural and working lands across rural America are an important part of our climate solution.

“[Soils] are the largest storage source for terrestrial carbon.
Karen Ross, Secretary, CA Dept. Food and Agriculture, March 12, 2019

“Opportunities for mitigation include … [C] sequestration in soils and biomass”
International Panel on Climate Change, 2014.

“Global leaders must make soil organic carbon a priority.”
“Scientists are … translating science into action.”
Johannes Lehmann and other scientists at international meeting, 2018.
Can Organic Practices Help Mitigate Climate Change?

- Carbon Sequestration
- Soil Nitrogen Management
- Reducing Other Greenhouse Gas Emissions

Yes!  
In multiple studies, soils from organic farms had:
- 13 – 19% higher total SOC than conventional
- 52% higher stable SOC
- 41% higher microbial biomass
- Additional 410 lb./ac-yr. SOC accrual
- Slightly lower N₂O emissions

Maybe not …
- Tillage for weed control burns up SOC.
- 19% yield gap increases GHG per unit output.
  ➢ Need cultivars adapted for organic
- Off-farm derived SOC is not sequestered C.
- “Organic by substitution” does not reduce net GHG.
  ➢ Sustainable organic
Integrated Organic Systems Build SOC

US Trials: organic adds 400 – 600 lb. SOC/ac-yr.

Key factors include:
- Cover crops and amendments
- Diverse rotation
- Perennial sod crop
- Reduced tillage when practical

![Cover crop](image1) + ![Compost](image2) = ![More soil carbon](image3)

Compost

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Stable SOC</td>
<td>• Composting process emits some GHG.</td>
</tr>
<tr>
<td>• Beneficial microbes</td>
<td>• Importing organic materials can deplete other acreage.</td>
</tr>
<tr>
<td>• Slow-release nutrients</td>
<td>• Can accrue excess soil P, suppress mycorrhizae.</td>
</tr>
<tr>
<td>• Composting on-farm manure stabilizes N.</td>
<td>- Calibrate rate based on soil test P.</td>
</tr>
<tr>
<td>• Diverts:</td>
<td></td>
</tr>
<tr>
<td>– Leaves, yard waste, food waste from landfill</td>
<td></td>
</tr>
<tr>
<td>– Manure from lagoons</td>
<td></td>
</tr>
</tbody>
</table>

![Composting process](image4)
Summary: Building SOC

- Apply NRCS Principles of Soil Health and NOP Soil Fertility and Crop Rotation Practice Standards.
  - *Diversify rotations.*
  - *Include deep rooted crops and perennial sod.*
- Use finished compost to stabilize SOC.
  - *A little goes a long way.*
- Use MIG rotational grazing for livestock.
  - *Silvopasture can further enhance SOC.*
- Plant erodible, depleted, marginal, or fragile land to forest, prairie, pasture, or perennial crops.

Summary: Preventing SOC Losses

- *Stop erosion* – the great SOC thief.
- Avoid excessive N and P.
- Avoid bare fallow.
- Keep orchard and vineyard floor in living plant cover.
- Avoid clearing forest or breaking sod, especially native prairie.
- Plant erodible, depleted, marginal, or fragile land to forest, prairie, pasture, or perennial crops.
What About Nitrous Oxide?

It’s not really a laughing matter for the climate.

Denitrification and Soil $N_2O$ Emissions

IPCC Models:
- Soils emit 1% of applied fertilizer N as $N_2O$.
- 0.75% of leached nitrate-N becomes $N_2O$.

Research findings:
- $N_2O$ emissions soar as N exceeds crop need.
- Soluble $N$ + limited $O_2$ + available organic C + active soil microbes $\rightarrow N_2O$

$N_2O$ is a product of denitrification, which occurs when wet or compacted soil limits oxygen, and microbes use nitrate-N as an oxygen source.
**N$_2$O in Organic Systems**

N$_2$O from organic N sources:
- Average 0.57% of applied N
- 0 – 0.3% for finished compost
- >1% for manure slurry

N2O risk factors in organic:
- High SOM
- Poultry litter + excess rain
- Legume sod plowdown
- Finer textured soils
- Heavy N feeder, e.g., broccoli

Plowing in a legume green manure can lead to a burst of N$_2$O emissions.

---

**Tightly Coupled N Cycling in Organic Tomato in California**

Study of 13 fields, three patterns:
- *N deficient* – Nitrate-N < 6 ppm, low SOC, low yield
- *N saturated* – Nitrate N > 6 ppm, moderate SOC, high yield, some N$_2$O risk
- *Tight N cycling* – Nitrate-N < 6 ppm, high SOC, **high yield with minimal N$_2$O risk**

Bowles et al., 2015. PLOS ONE.

Vigorous tomatoes grown on moderate C:N compost and no concentrated N
Limiting Nitrous Oxide: a Summary

- Provide crop-available N from SOM and slow-release sources.
- Encourage mycorrhizae, avoid excess P.
- Band concentrated N near crop row at low rates (20 – 50 lb N/ac).
- Avoid spreading manure or tilling-in legumes on wet soil, or before heavy rain.
- Mix legumes with grasses in annual and perennial cover crop plantings.
- Grow deep-rooted, N-demanding crops to “mop up” leftover soil N.

Pearl millet can retrieve nitrate-N to 6 ft depth.

Mitigating Methane Emissions

Livestock Production

Rice Production
Methane: the Bad News

Agricultural operations emit methane (CH$_4$) from:
- Livestock (enteric)
- Manure lagoons
- Rice paddies

Organic 100% grassfed dairy vs. conventional dairy:
- 30% more CH$_4$/cow
- 100% more CH$_4$/gallon milk
- N$_2$O hot spots in pasture

Cattle emit CH$_4$, whether pastured or confined.
Manure deposited near fence line may emit N$_2$O.

Methane: the Good News

Switching to a pasture-based system:
- Sequesters carbon in pasture
- Eliminates manure lagoons

Switching from continuous grazing to MIG rotational grazing:
- Sequesters > 1 ton SOC/ac-year
- Improves forage quality and quantity, meat and milk production
- Reduces enteric CH$_4$/cow by 30%
- Reduces N$_2$O hotspots

Multiple paddocks for MIG system
Healthy cows on resilient pasture
**Summary: Climate-friendly Livestock**

- Keep livestock on pasture as much as practical.
- Use MIG system adapted to your locale.
  - Ensure sufficient recovery period after grazing.
- If livestock are confined part of the year:
  - Compost manure, or
  - Capture lagoon CH$_4$ as fuel, or flare it to release less-harmful CO$_2$.
  - Spread manure only on well drained soil, at rates that will not develop excessive soil P.

---

**System of Rice Intensification**

The Method:
- Fields not flooded
- Seedlings set 1 ft. apart
- Compost for fertility

Results:
- Healthy soil, healthy roots
- Enhanced N use efficiency
- Much higher yields
- GHG reduced 60% (yield basis)

Farmer Moghanraj Yadav grows excellent SRI rice crop without flooding in Tamil Nadu, India.
Estimating the Farm’s GHG Footprint

Monitoring soil organic carbon:
- Total SOC (= SOM/2)
- Permanganate oxidizable C (POX-C)
- Soil respiration

Estimating Greenhouse Gas Emissions
- COMET Farm [http://cometfarm.nrel.colostate.edu/](http://cometfarm.nrel.colostate.edu/)
- Organic Farming Footprint [https://ofoot.wsu.edu/](https://ofoot.wsu.edu/)
- Denitrification-Decomposition Calculator (DNDC) [http://www.dndc.sr.unh.edu/](http://www.dndc.sr.unh.edu/)
- Northeast Dairy Emissions Estimator (NDEE) [http://nedairy.ags.io/](http://nedairy.ags.io/)

Research Frontiers in Climate Mitigation and Resilience

- Opportunities:
  - Enhanced SOC sequestration by deep-rooted crops
  - Enhanced plant-microbe partnership for SOC sequestration and nutrient efficiency
  - Tight N cycling in other crops & regions
  - Plant breeding for these traits and climate resilience
  - Livestock breeding for MIG systems
- Concerns:
  - Climate change impacts on SOC and N cycling
  - Soil inorganic (carbonate) C – losses in organic
Making Climate Mitigation Pay: Carbon Markets

- Farmers seek economic return for C sequestration.
- Many variables affect SOC sequestration, making it difficult to quantify for carbon markets.
- “Estimating … the anthropogenic component of … GHG fluxes [from agriculture, forestry, and other land uses] to the atmosphere … is difficult compared to other sectors.” (IPCC, 2014).

California’s Healthy Soils Program and Natural and Working Lands Strategy

Proceeds from the California Climate Investment (cap and trade) support farmers use of cover crops, compost, and mulch to reduce tillage and install conservation plantings. 
https://www.cdfa.ca.gov/oefi/healthysoils/.
Making Climate Mitigation Pay: Co-benefits of Best Practices

All practices covered today:
– Are compatible with NOP standards
– Build soil health and stress resilience
– Enhance long term yield stability
– Can enhance farm profits

Corn in conventional (left) and organic (right) treatments in Rodale trials during 2015 drought.

Download the Soil Health and Organic Farming Guides at www.ofrf.org.
Thank you to the following organizations and foundations for their long term support of OFRF.


Questions?