Meeting Weather Challenges in the Western U.S.
Organic Practices to Mitigate and Prepare for Climate Change

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How is Climate Change Impacting Organic Agriculture in the Western Region?

Farmer-identified
Research Needs
Organic Farmer Research Priorities in the Western Region

Soil health – 71%
- Practices to sequester soil organic carbon (SOC)
- Economic benefits for SOC

Irrigation and drought – 56%
- Irrigation efficiency
- Soil water retention
- Soil salinity
- Drought and pasture health

Available at http://ofrf.org/

Extremes of Drought and Flood

- “Drought...heat waves...costs [of] mitigation have me concerned I can no longer do this.”

- “Three years ago...drowning rain and lack of sun...this June was one in 400 year drought”
  Farmer quotes, NORA 2016

- “11.7 inches is the average...[with] climate change, last three years [were] 26 – 2.5 – 5.4 inches.”
  Doug Crabtree, Havre, MT, pers. comm.
Irrigation in the Era of Climate Change

• “The current drought has dramatically decreased irrigation water allocated to organic tomato growers.”
  Amelie Gaudin et al., 2018.

• “Irrigation is not truly sustainable...we need better practices that improve our water capture, retention, and cycling.”
  Farmer quote, NORA 2016, p. 25

Other Climate Related Concerns

• Impact of altered temperature patterns on chill hours for bud break in tree crops
• Need for new crops and cultivars to adapt
• New weed and insect pest species
• Increased disease pressure

Warmer winters may fail to meet chilling requirements for normal development in tree fruit and nut crops.
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>CO₂eq</th>
<th>CO₂-Ceq</th>
<th>Sources in Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1</td>
<td>1</td>
<td>• Fossil fuel – farm machinery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Embodied energy in inputs</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Lime, urea, field burning</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Losses of soil organic carbon (SOC) and biomass</td>
</tr>
<tr>
<td>CH₄</td>
<td>21</td>
<td>7.6 (CH₄-C)</td>
<td>• Livestock enteric methane</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Manure storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Paddy rice cultivation</td>
</tr>
<tr>
<td>N₂O</td>
<td>310</td>
<td>133 (N₂O-N)</td>
<td>• N-fertilized soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Manure (pasture &amp; storage)</td>
</tr>
</tbody>
</table>
Direct Agricultural GHG Emissions in the U.S. in 2017

CO₂ from farm machinery and embodied in inputs
Rice + misc.
Manure storage
Enteric CH₄
N₂O from soil

Accounts for ~10% of total U.S. GHG emissions.

Does not include CO₂ emissions from:
• Soil erosion.
• In-situ SOC losses.
• Breaking sod or clearing forest for agriculture.

Soil and the Global Carbon Cycle

Soil: 3,000 organic
940 inorganic

Vegetation 620
Atmosphere 790
Fossil Fuels 5,000
Oceans 38,000

C pools: billions of tons
Flows: billions of tons per year

The Carbon Cost of Clearing Land

30 – 50% SOC losses in 50 years

Cover crops
Diversified rotation
Compost

Reduced tillage
More soil carbon

Long term trials:
- Organic systems add 400 – 600 lb SOC/ac-yr.
- Can offset direct agricultural GHG
“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

Methane (CH$_4$)

In anaerobic conditions, soil microbes convert organic C into CH$_4$.

Agriculture emits CH$_4$ from:

- Livestock (enteric) ~500 lb per animal-year
- Manure lagoons ~ 10% of U.S. agricultural GHG
- Flooded rice paddies ~110 lb per acre-year

Cattle emit CH$_4$, whether pastured or confined.

Rice paddy soils convert organic residues to CH$_4$. 

ORGANIC FARMING RESEARCH FOUNDATION
Denitrification and Soil $\text{N}_2\text{O}$ Emissions

Soluble N + limited O$_2$ + available organic C + soil microbes $\rightarrow$ $\text{N}_2\text{O}$
- 80% water filled pore space (little at <60%)
- Compacted soil
- Fine-textured soils
- Little $\text{N}_2\text{O}$ if soil <6 ppm nitrate-N

IPCC Models for $\text{N}_2\text{O}$ emissions:
- Direct: 1% of applied fertilizer N
- Indirect: 0.75% of leached N

$\text{N}_2\text{O}$ increases as N > crop need

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.

N$_2$O risk factors in organic:
- Ample active SOM
- Poultry litter + excess rain
- Legume plowdown
- Heavy N feeder, e.g., broccoli

Plowing a legume green manure can lead to a burst of N$_2$O emissions.
Organic Farming Practices to Meet Climate Challenges

- Building Resilience through Healthy Soil
- Sequestering Carbon
- Mitigating Greenhouse Gases

Pop Quiz:

What sophisticated biotechnology shows the greatest promise to help humanity slow climate change and protect our food system against its effects?

*Hint: It is not a human invention.*
Living Plants:

**Build healthy, resilient soils**
- Foliage protects soil surface.
- Living roots:
  - Build SOM and soil structure.
  - Feed soil life.
  - Deepen soil profile.

**Sequester C**
- Photosynthesis converts CO$_2$ into organic C.
- Roots deliver organic C to soil.
- Deep roots build stable SOC below tillage depth.

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**How Roots Build SOC Throughout the Soil Profile**

- Soil biological activity is concentrated near the 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.
Rain soaks in. Healthy soil holds ample moisture and hosts myriad beneficial organisms. Crops are resilient to drought, disease, and other stresses. Healthy soil drains well and stays aerated.

### Soil Health and Climate Resilience

### Climate Benefits of Organic Practices

<table>
<thead>
<tr>
<th>Practices</th>
<th>Mitigation</th>
<th>Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tight rotation, sod, and cover crops</td>
<td>SOC, N₂O</td>
<td>Soil and crop health, drought tolerance</td>
</tr>
<tr>
<td>Crop diversification</td>
<td>SOC</td>
<td>Soil biodiversity and health, reduced risk</td>
</tr>
<tr>
<td>Nutrient management</td>
<td>N₂O</td>
<td>Rhizosphere health, nutrient cycling</td>
</tr>
<tr>
<td>Rotational grazing</td>
<td>SOC, CH₄</td>
<td>Drought resilience, forage and livestock health</td>
</tr>
<tr>
<td>Compost</td>
<td>SOC, CH₄</td>
<td>Soil and crop health</td>
</tr>
</tbody>
</table>

**Organic Farming Research Foundation**
Combine Practices to Sequester C

Continuous no-till, cash crop residues only: 510 lb C/ac-yr

Not stable

Cover crop: 135 – 195 lb C/ac-yr

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

Diversify the Rotation

Diversified crop rotation: 180 – 470 lb C/ac-yr
Make and Use Compost Wisely

- Stable SOC
- Beneficial microbes
- On-farm nutrient cycling
- Diverts:
  - Leaves, yard waste, food waste from landfill
  - Manure from lagoons
- Composting emits some GHG.
- Importing feedstock can deplete source acreage.
- Can accrue excess soil P, suppress mycorrhizae
  - Calibrate rate to soil test P

Manage N to Tame the N\textsubscript{2}O Beast

- Provide N from SOM and slow-release sources.
- Encourage mycorrhizae, avoid excess P.
- Band concentrated N in crop rows at low rates (<50 lb/ac).
- Avoid spreading manure or tilling-in legumes during wet conditions.
- Sow legumes with grasses in cover crop or sod plantings.
- Grow deep-rooted, N-demanding crops to “mop up” leftover N.
System of Rice Intensification

The Method:
• Fields not flooded
• Seedlings set 1 foot apart
• Compost for fertility

Results:
• Healthy soil, healthy roots
• Enhanced N use efficiency
• Much higher yields
• Much less CH\textsubscript{4}
• 60% less GHG / ton yield

Farmer Moghanraj Yadhav grows excellent SRI rice crop without flooding in Tamil Nadu, India.

Restore Soils with Livestock

Management-intensive rotational grazing (MIG) builds ≥ 2,000 lb C/ac-yr. Silvopasture (top right) can add 3,900 lb C/ac-yr. Multispecies grazing (right) builds soil diversity and resilience.
MIG vs. Continuous Grazing:

- Sequesters > 1 ton SOC/ac-year.
- Improves forage quality, and meat and milk production.
- Reduces enteric CH$_4$/cow by 30%.
- Distributes manure and reduces N$_2$O hotspots.

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Plant Perennial Crops and Conservation Buffers

- 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)
Technical and Financial Assistance in Meeting the Climate Challenge

• Estimating Benefits
• Federal Conservation Programs
• State and Local Programs

Estimating GHG Footprint and Documenting Benefits of Practices

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/ - GHG decision support tool, updated to include MIG, cover crops, and organic amendments
• Organic Farming Footprint https://ofoot.wsu.edu/ - estimates SOC and net GHG for organic systems
NRCS Conservation Programs

CSP and EQIP support:
- Cover cropping
- Improved crop rotation
- Advanced grazing system
- Conservation buffers
- Comprehensive conservation planning

2018 Farm Bill:
- Emphasis on soil health
- Address “increasing weather volatility”

Soil Health Principles

- Keep soil covered
- Maintain living roots
- Minimize disturbance
- Diversify crops

California Healthy Soils Program

Soil health practices to build SOC and reduce GHG
- Incentives for practices
- Demo projects
- Measure/estimate GHG benefits
- $15M for 2019, part from state cap & trade
- https://www.cdfa.ca.gov/efi/healthysoils/
Other State Soil Health Programs

- New Mexico Healthy Soils Program
  - Soil Health Act 2019 - $455,000 of funding
  - Research, monitoring, education, tech assistance

  - Research best practices for Hawaii
  - Carbon farming certificate and carbon credits

- Soil Health Institute listing of additional State agency and University programs, including the land grant universities in CA, CO, MT, and WA: https://soilhealthinstitute.org/resources/catalog/

Meeting Climate Challenges in the Western Region

Research Findings and Farmer Experiences
Saving Water through Soil Health and Deficit Irrigation

OFRF-funded project
*Can healthy soil improve water use efficiency and resilience in organic tomato?*

Scott Park’s soil health practices:
• Diverse crop rotation
• Winter cover crops
• Compost, microbial inoculant
• Reduced till, controlled traffic

2016 Trial: Deficit Irrigation at Park Farm Organics

Irrigation treatments:
• Standard (stop 30 days before harvest)
• Deficit (stop 45 days before harvest)

Outcomes with deficit irrigation:
• Saved 0.5 acre-ft of water
• Yield and quality unaffected
• End-of-season soil microbial activity doubled
• Nitrate-N significantly less
2017: Organic Enhances Water Efficiency

- Organic used much less water.
- Organic doubled soil moisture reserves.
- Yields were similar across all treatments.

Based on slides by Dr. Amelie Gaudin

Vital Role of Winter Cover Crops during California’s Rainy Season

Cover Crops

Poor Soil Structure & Poor Soil Health

Healthy Soil with Good Structure

Photo: Z. Kabir, NRCS, Feb 07, 2017
N$_2$O Challenge in Organic Broccoli

Organic N rate trials in WA:
- Linear yield response to > 200 lb N/ac
- $4 - 34$ return per $1$ on N.

Organic broccoli in CA, 215 lb N/ac:
- Leached 180 lb N/ac
- Emitted 23 lb N/ac as N$_2$O
- Net loss of SOM

2/3 of N as compost and cover crops:
- Increased SOM
- Cut N$_2$O by half, leaching same
Winter Cover Crop Recycles N

Spring lettuce ➔ Fall broccoli ➔ Winter cover: rye + legume mix

N recovery, SOM, higher lettuce yield

Sarah Brown, Oregon Tilth


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, risk of $N_2O$ emissions

• *Tight N cycling* – Nitrate-N < 6 ppm, high SOC, high yield with minimal $N_2O$ risk

Bowles et al., 2015. PLOS ONE.
Balancing C and N in Organic Inputs

Puyallup, WA (maritime) organic vegetable rotations receiving:

- Compost, Moderate C:N
- Fertilizer, Low C:N

or

Poultry litter

After 11 years, the higher-C compost resulted in:

- Better soil structure and water infiltration.
- 35% higher microbial activity.
- 43% higher total SOC.
- Changes in soil biota that could mitigate N₂O emissions.

More Compost Research Findings

- In Utah dryland, one-time heavy application of compost doubled topsoil SOC and organic wheat yields for 15 years.
- In California rangeland, one compost application enhanced plant production and net SOC storage.
- LCA: composting manure and yard waste avoids massive GHG emissions from lagoon and landfill.
- A little compost can enhance SOC accrual from cover crops and other practices.
Living Cover Builds Orchard and Vineyard SOC and Resilience

- Bare orchard floor soils can lose half their SOC.
- Living cover improved soil and tree health in Utah orchards.
- Living mulch in Oregon cherry orchard enhanced SOM, N cycling, and microbial activity.
- Bonterra Vineyards found 9 – 12% higher SOC in organic systems.

Sequestering SOC in Dry Regions: Can Deep Roots Backfire?

Dryland challenge:
- Wheat-fallow depletes SOC.
- Cover crops can deplete moisture and hurt yields.
- Alfalfa is one of the worst.
- Barley, medic, millet, and cowpea conserve moisture.

Sunflower and pearl millet root deep; sunflower uses a lot of moisture; millet is water-efficient.
Building SOC on Limited Rainfall

Diverse rotations, covers terminated by blade plow, intercrops (kamut-flax in photo, left), and no fallow enhanced SOC by 27% in 10 years on 11” rain/year at Vilicus Farms in MT. A crop-livestock integrated system with MIG, no till, and high crop diversity tripled SOC in 20 years near Bismarck, ND (16” moisture/year).

Some Unanswered Questions

Research Needs
• Many soils of drier regions are rich in carbonates, or soil inorganic carbon (SIC).
• Lowering soil pH could convert it to CO$_2$.
• Organic systems lost 9 – 14 tons SIC/ac in 3 out of 7 studies.
• Research on SIC conservation is urgently needed.

SOC Saturation

1. Depleted cropland → permanent pasture
2. Cropland → MIG pasture
3. Continuous no-till crops
4. Organic cropping system
5. Diversified rotation

Steady state SOC:
• Cropland ~55% of native
• Best soil health mgmt. → 85%
• Future innovation → 100%?
Will Climate Change Itself Make Mitigation More Difficult?

- Warming temperatures will accelerate SOC oxidation, especially in colder climates.
- Thawing of permafrost and rapid oxidation of peat soils may cause large global SOC losses.
- $\text{N}_2\text{O}$ emissions increase about 20% for each $1^\circ\text{C}$ (1.8°F) increase in mean July temperatures.
- One field study suggests that increasing atmospheric $\text{CO}_2$ may accelerate SOC losses.
- Organic practices are especially beneficial to SOC and microbial activity in warm climates.

Research Needs and Opportunities

- Crop breeding for:
  - Climate resilience
  - Nutrient-efficiency
  - Climate-friendly organic systems
- Deep roots for SOC sequestration
- Tightly coupled N cycling
- Farmer payment for ecosystem services
Questions?

Download the Soil Health and Organic Farming Guides at www.ofrf.org

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