

Organic Soil Health Practices for Water Management and Water Quality



Mark Schonbeck
Research Associate

June 26, 2023



Mark Schonbeck

Mark Schonbeck has worked for 35 years as a researcher, consultant, educator, and advocate for sustainable and organic agriculture. He works one-on-one with farmers and homesteaders, taking a site-specific approach to soil test interpretation and organic soil, nutrient, and weed management for vegetables and other crops. In his capacity as Research Associate with Organic Farming Research Foundation, he develops research-based education materials including a series of practical guides on *Soil Health and Organic Farming*, available at <http://ofrf.org/>.

In the past, Mark has led or participated in several on-farm research projects conducted by Virginia Association for Biological Farming and collaborated with them and National Center for Appropriate Technology to help our agency Natural programs better serve organic producers.

Mark also serves as policy liaison with National Sustainable Agriculture Coalition. He also works with OFRF to develop policy recommendations to help organic producers mitigate the impacts of climate change on their operations and the communities they serve.



Water is Essential

- Without adequate and timely moisture, crops cannot grow and yield, no matter how healthy the soil or how skilled the farmer.
- Too much water at once can also spell disaster.
- *Can organic soil health practices buffer the farm against drought and deluge?*



Organic vegetable crops thriving in healthy, moist soil. But what if it does not rain?

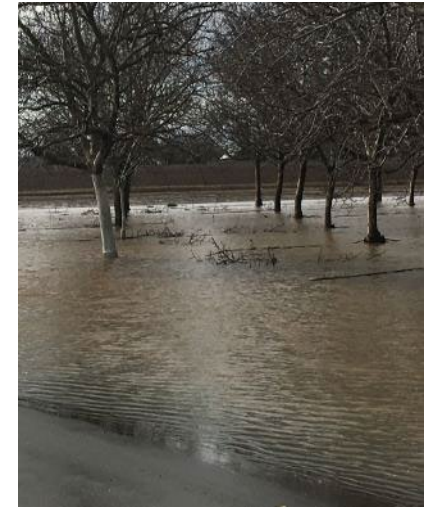
Water, Agricultural Production, and Soil Health

Drought:

- Causes crop and livestock losses.
- Hinders soil microbial processes.
- Reduces plant biomass inputs to soil.
- Increases risks of wind erosion and wildfire.

Too much rain:

- Delays planting, hurts yields.
- Transports nutrients by leaching and runoff.
- Increases water erosion.
- May damage soil structure and plant roots.



Prolonged drought degrades vegetative cover, depletes soil life, and leaves soil exposed to wind erosion (left). Ponding from excess rain disrupts soil biology and causes N losses by denitrification (right).

Irrigation Challenges

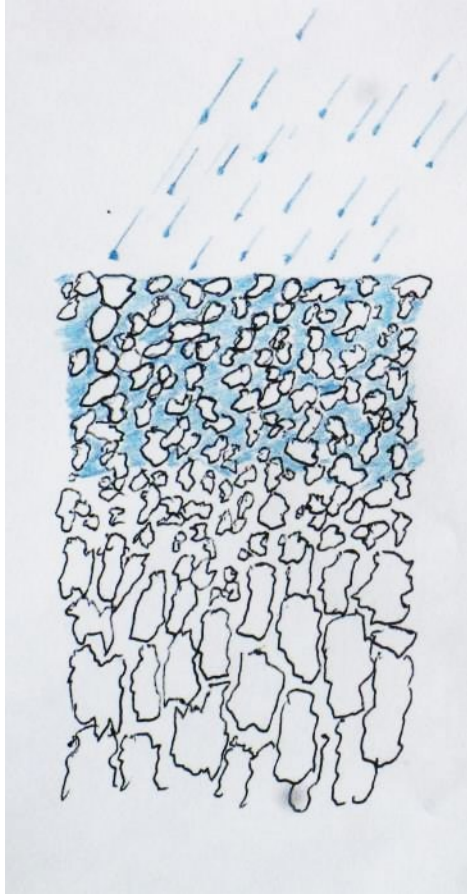
- Essential for most crops in low-rainfall areas.
- Adds to production costs.
- Resource depletion (aquifers, rivers).
 - Regulatory limits on water use.
- Nutrient losses in drainage and tailwater.
- Soil salinization from irrigation with groundwater
 - Especially in arid regions and high tunnels.



Soil Moisture 101

The effects of inherent and dynamic (management-related) soil properties on plant-available water

What Happens in Soil When it Rains

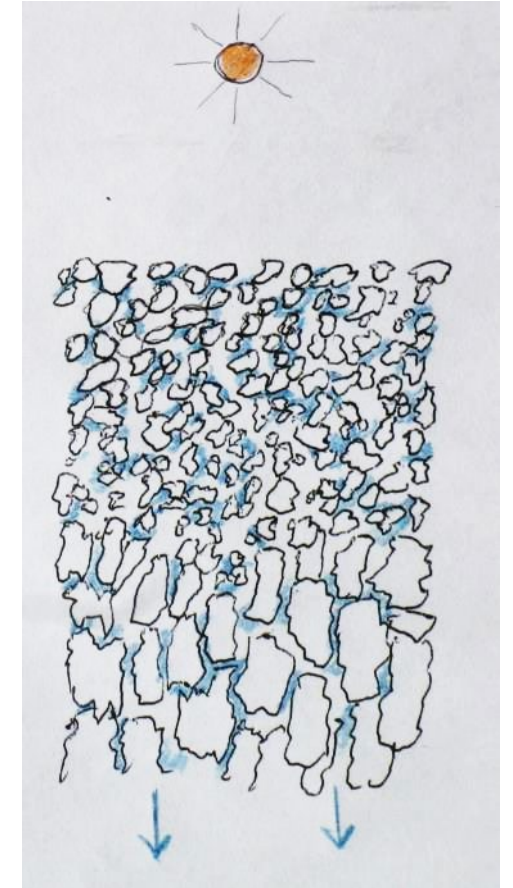


During a rain event, water fills soil pore space from surface downward (left).

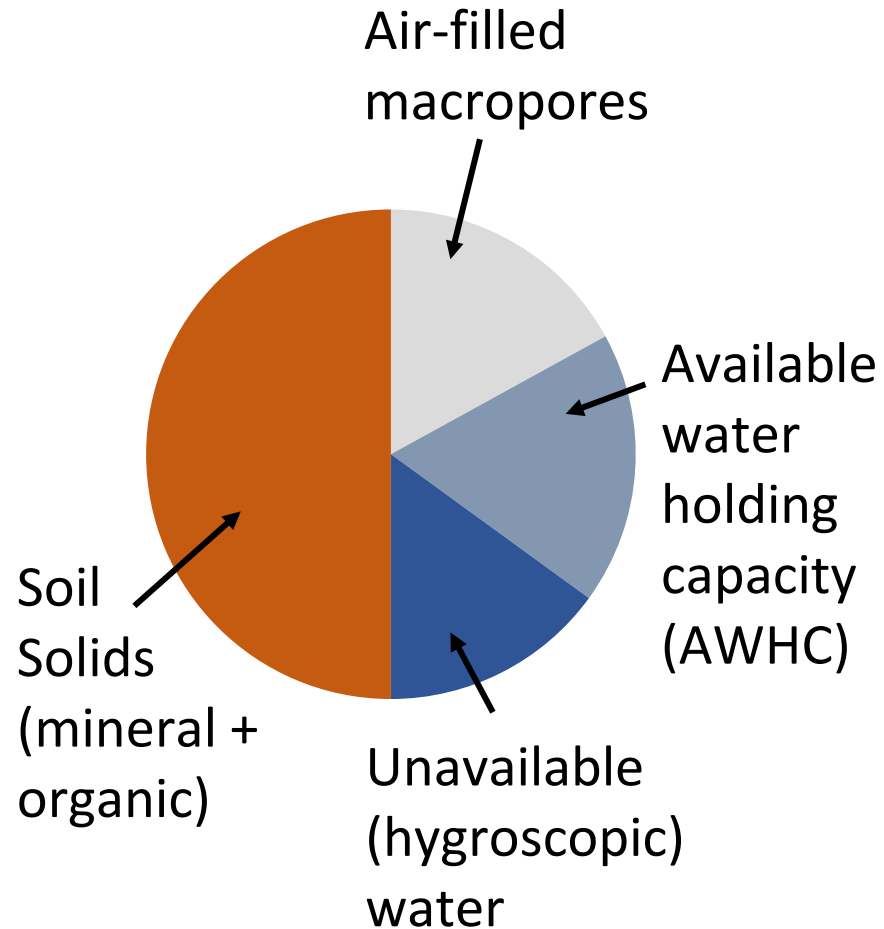
Excess water drains from larger pores and moves deeper into the soil (right).

Plant-available capillary water remains in smaller pores (right).

Water held tightly in the smallest pores (hygroscopic water) is not available to crops.



Inherent Soil Properties and Water Holding Capacity



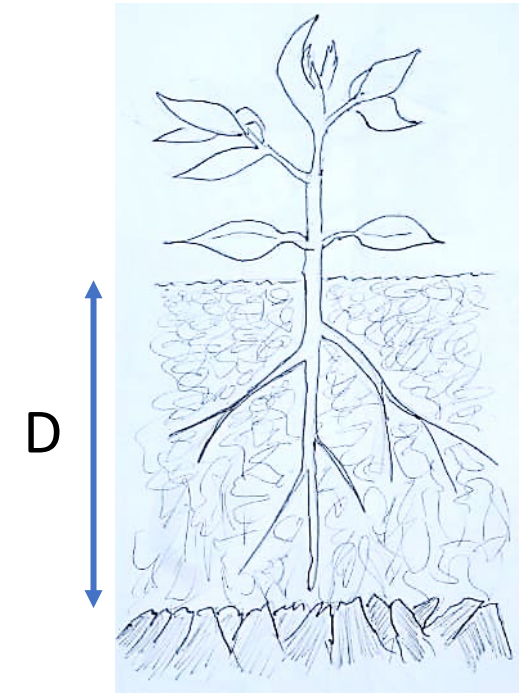
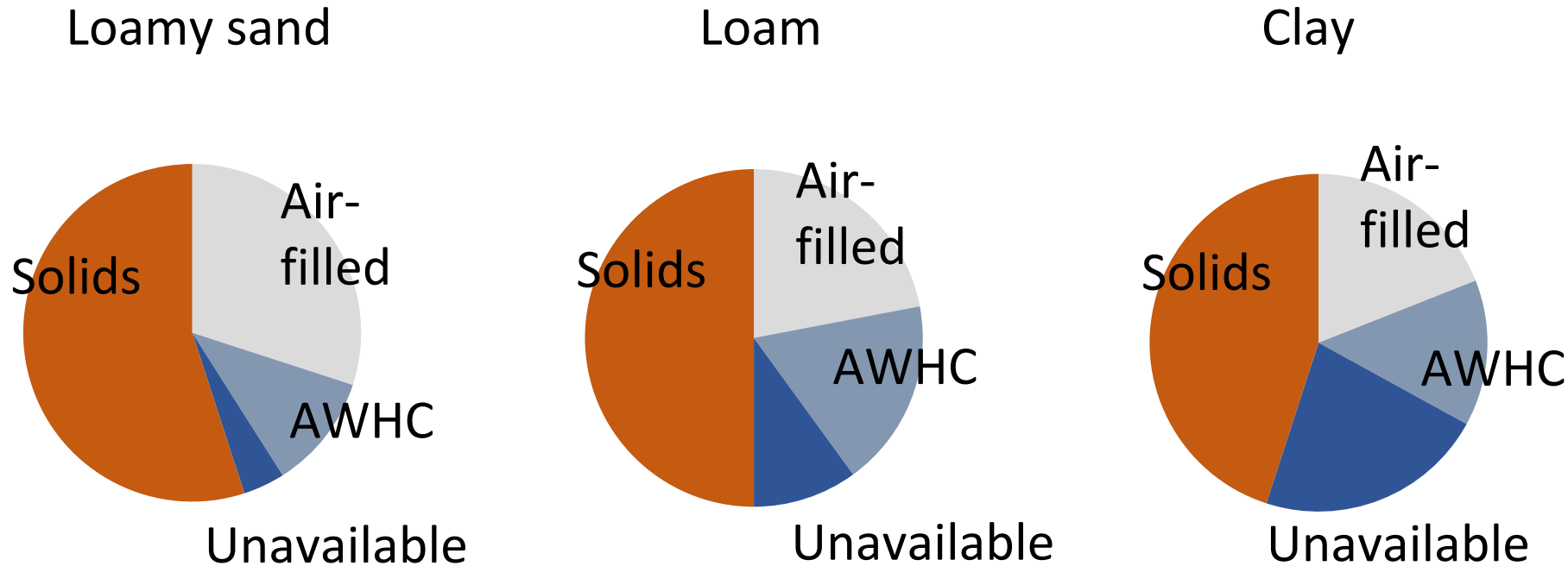
Factors influencing plant-available water:

- Soil texture
- Soil depth and profile
- Drainage, permeability
- Depth to root-restrictive layer



Soil profile in North Carolina coastal plain, showing root growth through the A (top) horizon and into the B (subsurface) horizon.

Soil Texture, Depth to Root-Restrictive Layer, and AWHC

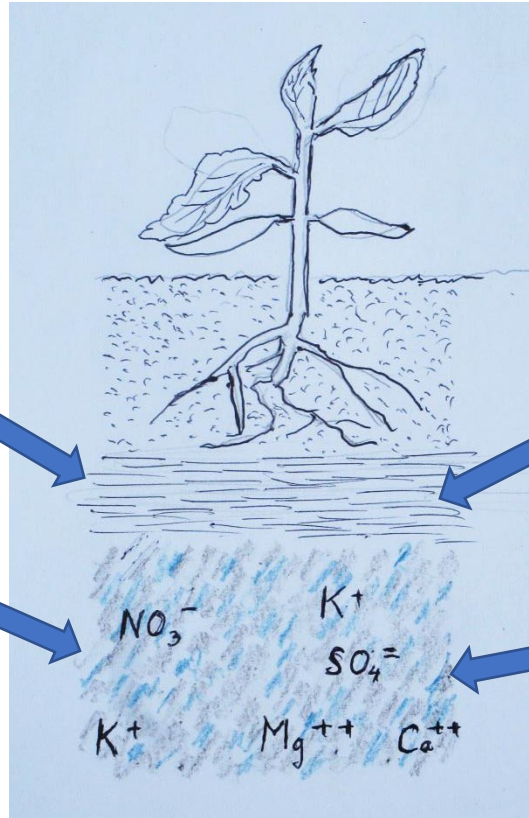


$$\text{Plant available water} = \% \text{ AWHC} \times \text{depth } (D)$$

Soil Profile and Plant Available Water

Example: Norfolk sandy loam.
Carolinas, coastal plain.

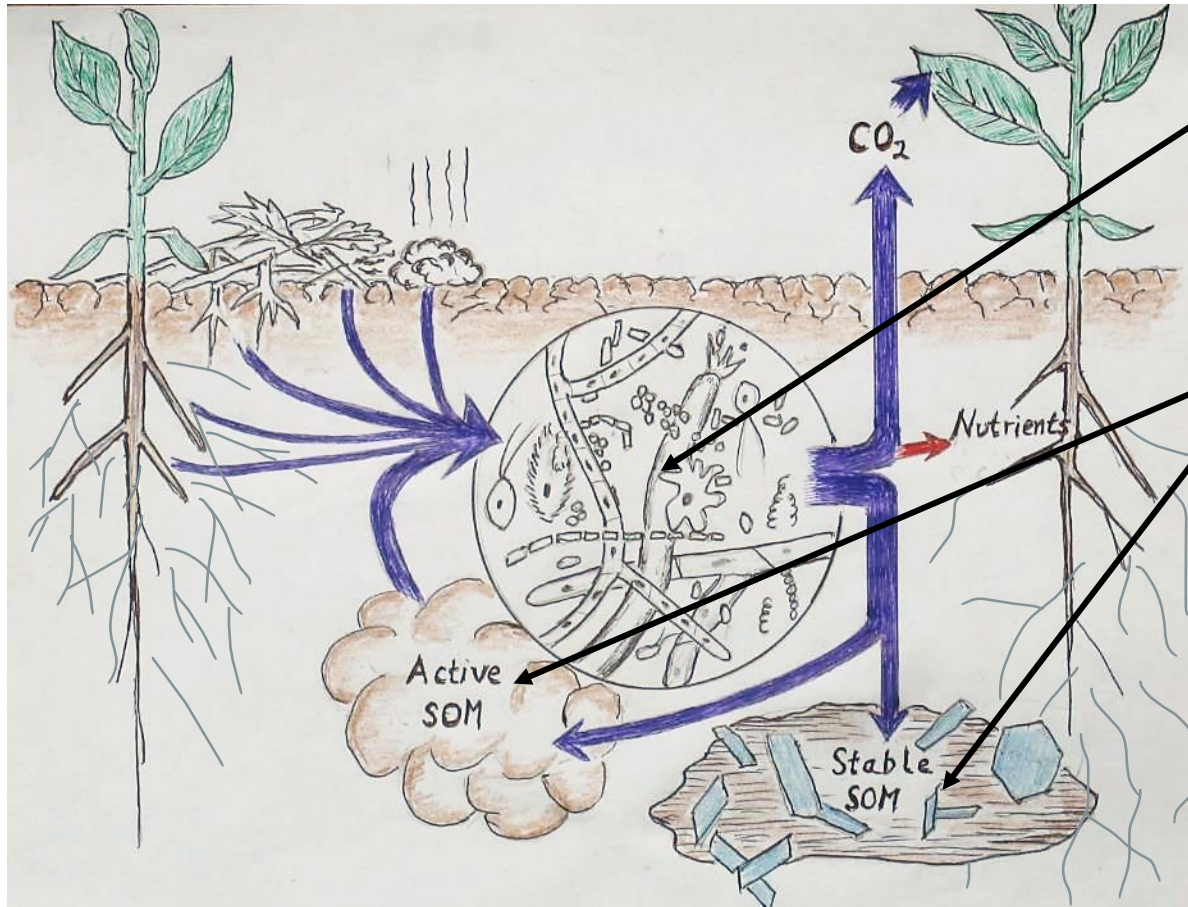
- Ultisol (highly weathered) .
- Compaction-prone E horizon below A horizon.
- Roots cannot access water and nutrients in B horizon.
- Annual subsoiling needed?
- Winter cover crops penetrate E horizon and create channels for production crops.



Example: Chualar loamy sand
Salinas Valley, California.

- Mollisol with clay-enriched (argillic) B horizon.
- Dense clay layer at 30" is water-permeable but restricts root penetration.
- Winter rains leach nutrients beyond reach of crop roots.
- Winter cover crops take up and hold N against leaching.

Dynamic Soil Properties and Available Water Holding Capacity

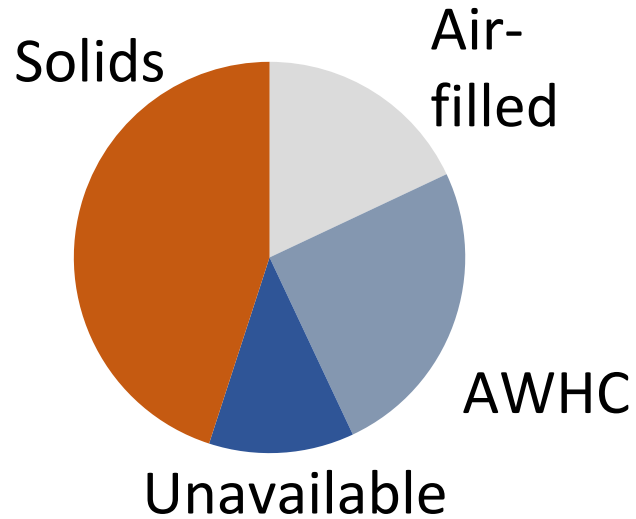


Soil microbes continually **regenerate soil aggregates and pore space** as they process organic residues into soil organic matter (SOM)

AWHC increases by 4% of soil volume for each 1% increase in SOM. To build AWHC:

- *Maintain living roots!*
- *Cover crops*
- *Organic amendments*
- *Minimize soil disturbances: tillage, traffic, fertilizer, pesticides*

Water Relations in Healthy, Biologically Active Soil



Soil life maintains aggregates, reduces bulk density, and expands pore space.

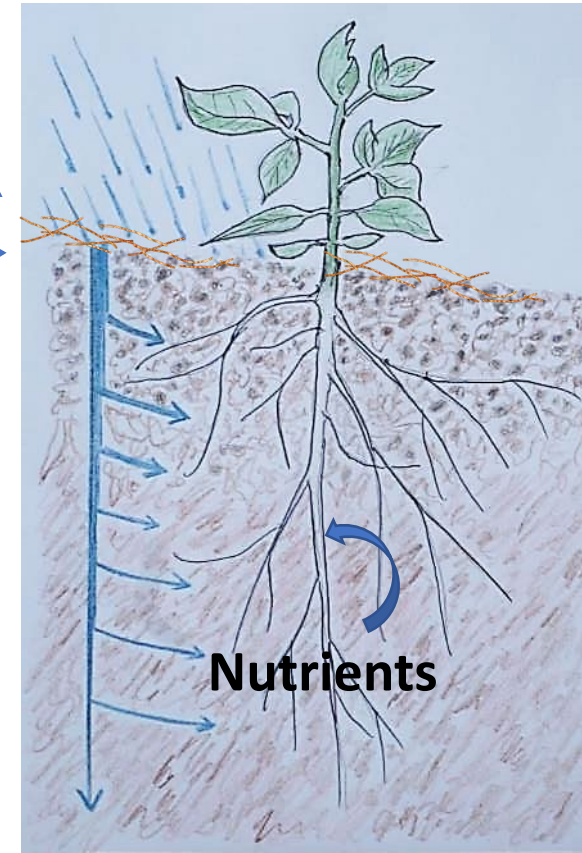
Surface protected

Rapid infiltration

Good structure and porosity.

*Moisture retained.
Unrestricted root growth.*

Minimal leaching

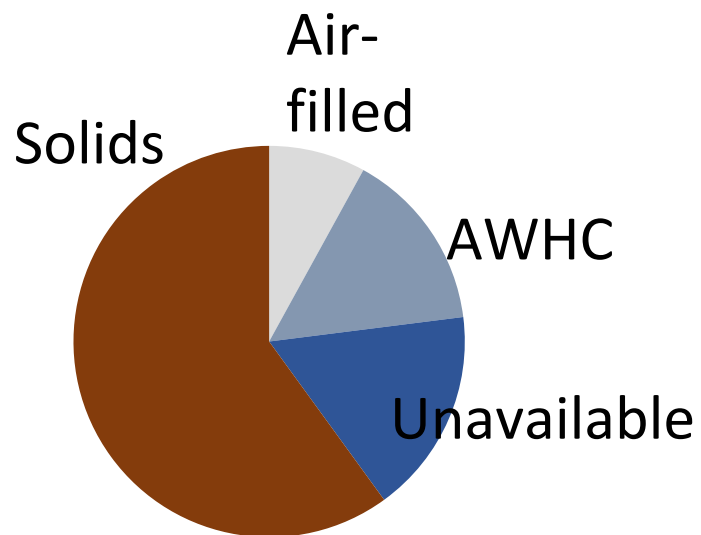


How Healthy Soils Keep Crops Watered

- Higher soil organic matter (SOM) →
Increasing SOM 1% in top 12" adds ~ 0.5" plant-available water .
- Network of pores open to surface →
Rainfall and irrigation infiltrate easily.
- Well aggregated, low bulk density →
Soil has high AWHC yet drains well.
- High biological activity and biodiversity →
Maintains SOM, structure, and pore space.
- Entire soil profile open to root growth →
Crops access deep moisture reserves.



Water Relations in Compacted or Crusted Soil



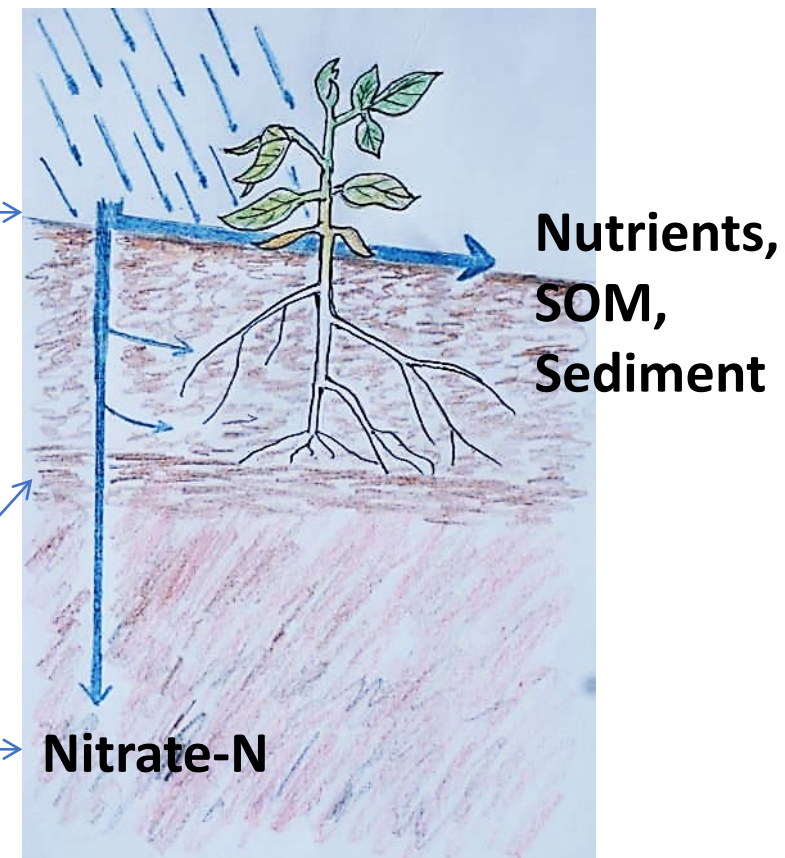
Excessive tillage or bare fallow degrades soil structure and collapses pore space.

Surface crust, rain runs off.

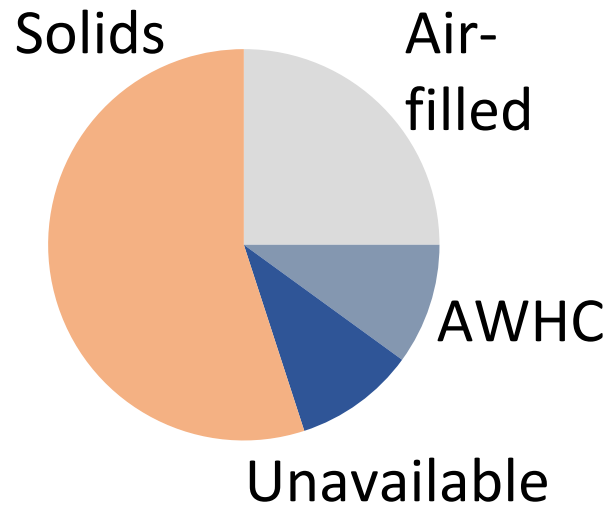
Less water stored.

Plowpan blocks root growth, slows water infiltration.

Nutrients may leach



Water Relations in a Depleted Soil



Inadequate plant biomass, diversity, and living root can reduce AWHC even when compaction is not present

Rain enters soil, but less is retained because of low SOM and biological activity, and fewer small pores.

Moisture and nutrients are lost to leaching.



Soil Management and Resilience to Drought and Deluge

Rodale Institute



Z. Kabir, NRCS, Davis, CA

In the Rodale long-term farming systems trial (1980-present), a diverse organic crop rotation with cover crops and organic amendments improved soil AWHC and sustained corn through a drought in 2015 (A) while conventional corn suffered a 24% yield loss (B). In central California, keeping almond orchard floor in living cover allowed a heavy rainfall to soak in (C), while a nearby clean-fallow almond orchard ponded badly (D).

Climate Change

21st Century monkey-wrench ups the ante for soil health and water management

How Climate Change Threatens Soil Health and Water Supply

- Increased drought and heat (especially Western region).
- Reduced mountain snowpack → less irrigation water in Western region.
- “Flash drought” – abrupt shift from wet to dry (e.g., in the South in 2019).
- More intense rainfalls and storms (Midwest, Northeast, South).
- Phenomenal California snowpack in 2023 – *can their soils absorb it all?*

Susan Tallman, NCAT



Extreme drought leaves soil without living cover and starves soil life (left). Intense rainfall on exposed soil seals surface pores, runs off, and erodes soil (right).

Extreme Rainfall can Degrade Soil Structure



Cultivation (left) leaves the soil surface vulnerable to surface sealing. Degraded soil structure slows drainage, favors certain weeds like yellow nutsedge (right), and reduces AWHC and drought resilience.

Pennsylvania Soil Health Benchmark Study (100+ farms):

- High-intensity rainstorms and record annual total rainfall in 2018.
- Steep (>50%) drop in aggregate stability in annual crop rotations.
- Planting and harvest operations on wet soil degraded aggregates in no-till.
- Partial recovery in aggregation during 2019 with normal rainfall.
- Pasture soils much less affected.

What Organic Farmers Say about Water, Weeds and Climate



Water-related production challenges:

- Controlling weeds – 67% of respondents
- Adapting to climate change – 36% (South – 54%)
- Drought management – 26% (West – 36%)
- Irrigation water use – 19% (Pacific states – 26%)

“When we’re facing a drought, [weeds are] the biggest thing we face”

“We have seen ...beautiful weather to start planting, and then six to eight inches in one month of rain.”

“ We [are now] using a lot of plasticulture ... because of saturated soil ... crop loss from microbursts and tons of rain ... climate change issues.”

Farmer Adaptation to Climate Change in the Northeast

- More frequent droughts and torrential rains
- Crop insurance claims in Northeast, 2013-16:
38% drought, 34% excess rain, 28% all other.
- Response of NY farmers to 2016 drought:
32% – build SOM, soil health
26% – install irrigation.
- Response of NY farmers to 2017 floods:
10% – build SOM to reduce erosion
70% noted flood resilience from soil health practices.

Cover Crop Confers Flood Resilience in Floyd County, VA



A cover crop of sorghum-sudangrass was planted in July immediately after potato harvest in this community garden in Floyd, VA. It reached 4 feet by late September (A). When seven inches of rain fell on an already rain-soaked region on Sept. 29, the river raged three feet deep through the field (B), pushed the fence over (C), and flattened the cover crop (D). However, not one shovelful of soil was lost, and soil drainage, aeration, and health were soon restored.

Climate Disruption Hits USA Organic Research: Lessons in Resilience

- One out of six USDA organic research projects impacted by weather extremes related to climate change.
- Mainly drought or excess rain – some hit by both at different times.
- Crop failures due to “the ongoing 1000-year drought affecting the ... Northwest region” (Reeve et al., 2022).
- “Severe drought hampered study sites ... wheat failed at Lubbock ... all crops at Vernon were replanted due to extreme weed pressure” (DeLaune, 2022).



- *Compost improved SOM, water permeability and wheat yields in drought (Reeve et al., 2022).*
- *Diverse rotation improved soil AWHC over continuous cotton in Texas (DeLaune, 2022).*

Managing Water Quantity and Quality in Organic Farming Systems

OFRF organic survey findings

USDA National Organic Standards

Best organic soil health practices for water management

Water Conservation in Organic Farming



By Lauren Snyder, Mark Schonbeck, and Thelma Velez Brise Tencer, Project Director

Adoption of water conservation practices such as drip irrigation, mulching, drought-resilient crops, etc.:

- Nationwide – 54% of survey respondents
- West, Great Plains and South – 64-68%
- Corn Belt – 22%
- Great Lakes and Northeast – 38-46%
- Specialty crop farmers (nationwide) – 67-71%

Implementation of practices to protect water quality:

- Cover cropping – 68%
- Crop rotation – 81%
- Conservation buffer plantings – 74%

NRCS Soil Health Principles, Soil Water, and Organic Practices

Soil Health Principle	Benefits to AWHC	Organic Practices
Keep soil covered	Prevents crusting, enhances water infiltration	Cover cropping, mulching, tight crop rotations
Maintain living roots	Feeds soil life, builds SOM, creates pore space and channels	Cover cropping, relay planting, crop rotation with perennial sod
Maximize diversity	Utilizes soil moisture efficiently, support soil microbial diversity and function	Crop rotation, intercropping, deep- and shallow-rooted crops, crop-livestock integration
Minimize disturbance	Protects soil life, soil structure, and porosity; prevents erosion, compaction, and crusting	Reduced tillage, non-use of synthetics, judicious use of organic nutrient sources

Cover Crops and Soil Water

Cover crops:

- Prevent runoff and erosion.
- Feed soil life, build SOM, enhance AWHC.
- Create root channels, maintain open pore structure.
- Enhance water infiltration and drainage.
- Absorb excess nutrients.
- Penetrate subsurface hardpan.
- Enhance future crop access to deep moisture reserves.
- Consume soil moisture while they are growing.



A mature cover crop of triticale + field pea.

Rye Cover Crop Enhances Soil Moisture and Cotton Yields

South Carolina coastal plain, sandy soils with compacted E horizon

Usually require annual subsoiling to sustain yields.

Winter rye cover crops (top right):

- Increased SOM by 0.5% and water content by 1 – 1.5 in top 18 inches.
- Relieved compaction, allowing cotton (lower right) to access subsoil moisture.
- Increased no-till cotton yields 38%.



Marshall et al., 2016. Open Journal of Soil Science 6: 149-158.

<http://dx.doi.org/10.4236/ojss.2016.610015>

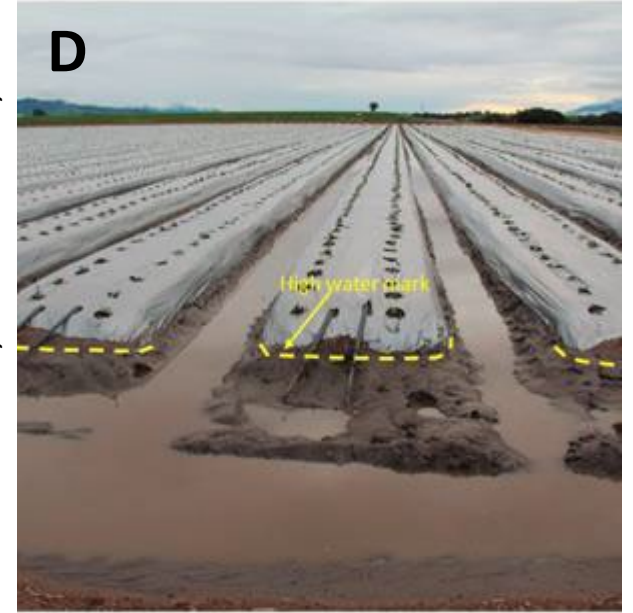
Mulching and Soil Water



Carol Shennan, UC Santa Cruz



Eric Brennan, USDA Salinas, CA



Organic mulches such as straw (A) enhance water infiltration, slow evaporation, hinder weeds, and conserve moisture. Weed mat (B) blocks weeds and is water permeable. Plastic film mulch (C) blocks weeds and retains existing soil moisture but excludes rainfall and requires drip irrigation under the film. Runoff from plastic mulched beds can pond in alleys and carry off nutrients and soil, as seen after a 0.4 inch rainfall in Salinas, CA (D).

Compost, Manure, and Soil Water

Compost and manure:

- Work with cover crops to build soil life, soil structure, and AWHC.
- SOM from finished compost > solid manure + bedding > poultry litter > manure slurry, anaerobic digestate

More is not always better:

- Excess P inhibits mycorrhizal fungi, may reduce crop drought resilience.
- Nutrient surpluses may run off to surface water or leach to groundwater.



Compost made from yard trimmings and food waste has a balanced C:N ratio that builds SOM.

Reducing Tillage to Conserve Soil Water-holding Capacity

- Mulch-till leaves >30% residue cover.
- Ridge till or strip till leaves alleys undisturbed.
- Rotary spader reduces compaction.
- Rototiller can be geared down to conserve aggregates.
- Sweep plow undercutter leaves residues on surface, conserves moisture.
- Shallow (<6 inches) non-inversion tillage can double soil microbial biomass over moldboard plow.

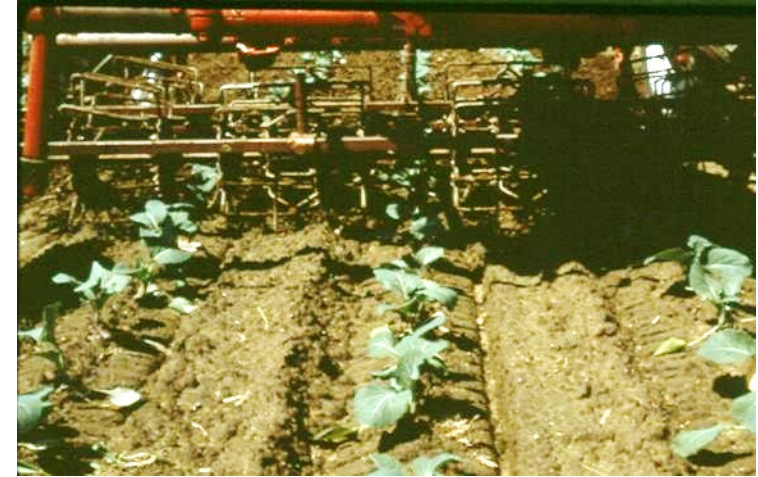


Strip tillage through roll-
crimped cover crop.

Cultivation and Soil Water

Shallow cultivation:

- Knocks out weed competition for moisture.
- Repeated passes can lead to surface sealing and hindered moisture infiltration.



Organic weed IPM to reduce need for cultivation:

- Strategic crop rotation, cover crops
- Preventing seed set
- Mulching
- Mowing
- Grazing
- Flame weeding, steam, etc.



Livestock Grazing and Soil Moisture

Advanced adaptive grazing management:

- Rotational grazing with sufficiently long recovery period builds robust, drought-resilient forage with extensive, deep root systems.
- Builds SOM and AWHC.
- Yields high quality forage.
- Distributes manure, protects water quality.
- Grazing system and rest periods must be regionally adapted and responsive to current weather conditions.



Rotational grazing systems that move herds to fresh grass every 1-3 days help livestock operations withstand drought.

USDA National Organic Standards on Water Resources

Production practices ... must maintain or improve the natural resources of the operation, including soil and water quality.

[B]oundaries and buffer zones such as runoff diversions to prevent ... contact with a prohibited substance.

[M]anage plant and animal materials ... in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or ... prohibited substances.

[I]mplement a crop rotation ... [to] manage deficient or excess plant nutrients.

The producer ... must manage pastures and other outdoor access areas in a manner that does not put soil or water quality at risk.

National Organic Program (NOP) Regulations, §205.200 General, §205.203 Land requirements, §205.203 Soil fertility and crop nutrient management, §205.205 Crop rotation, §205.239 Livestock living conditions

Water Quality and Organic Farming

Production affects water quality:

- Nitrate leaching
- Nutrients in runoff
- Pathogens (manure)
- Sediment (eroded soil)

Water quality affects soil and crops:

- Salinity, alkalinity, sodium
- Pathogens, contaminants

Healthy soil:

- Absorbs rainfall, reduces runoff
- Retains water and nutrients



Organic farmers build healthy soil and manage organic nutrient sources with care to protect water quality.

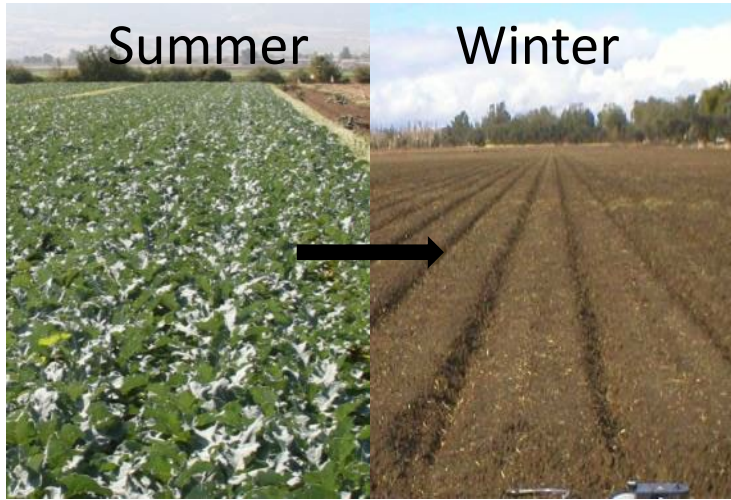
Water Quality Concerns in Different Rainfall Regimes

*Warm-temperate rainy climate
Floyd County, VA: ~45"/year
rainfall > evaporation*



Nitrate-N leaches
to groundwater

*Mediterranean climate
Davis, CA: 19.2"/year
winter rain much > evaporation*



Leftover nitrate-N
rapidly leached



*Semiarid climate
Hill County, MT: 11"/year
rainfall < evaporation*



Soluble salts move
toward soil surface

Cover Crops and Soil Water in Challenging Climates

Dryland grain production in semiarid climates

Vegetable production in Mediterranean climates

Dryland Challenge

In dry regions, cover crops build SOM and AWHC – and may also:

- Produce less biomass.
- Suffer from weed pressure.
- Take moisture from cash crops.

During bare (tilled or herbicide) fallow:

- Soils lose SOM, AWHC, fertility.
- Wind erosion increases.

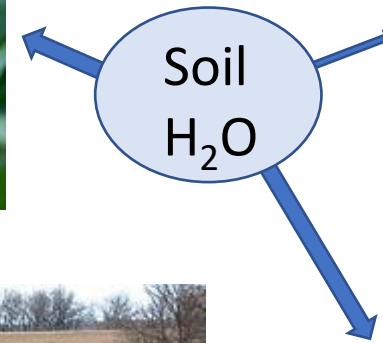
Cover crop



Grain crop



Doug Crabtree



Weeds



Cover Crops for Dryland Production in Semiarid Climates

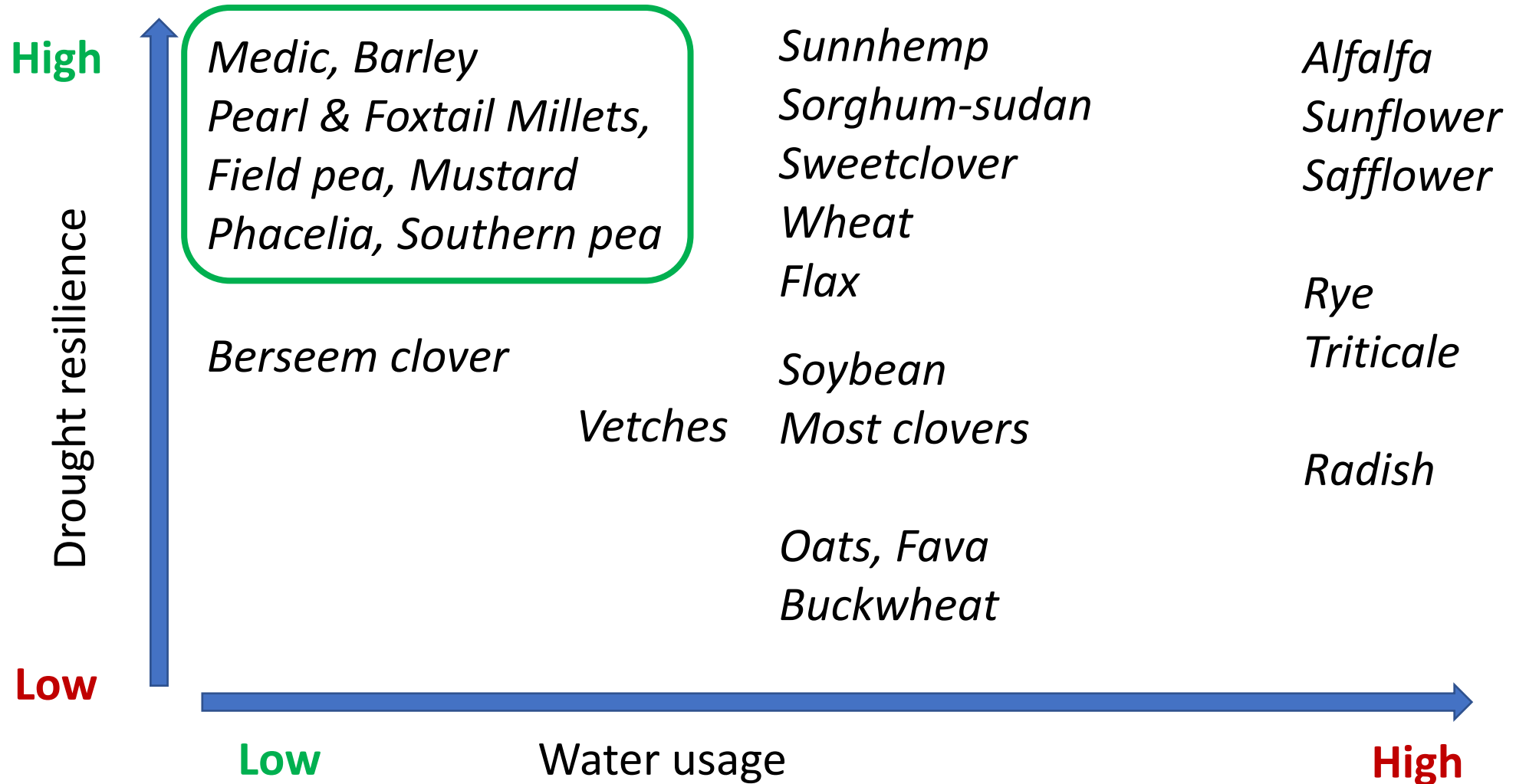
- Drought hardy
- Good biomass
- Low moisture demand
- Residue cover in dry season
- *Best species selection depends on soil type, climate, and seasonal rainfall pattern.*

New Mexico Stat U



Pearl millet (left) combines high biomass and water use efficiency. Winter field pea (right) shows promise as a winter cover crop in dryland rotations.

Cover Crops for Dryland Production in Semiarid Climates



Cover Crops for Moisture-Limited Regions: California's Central Valley

- Limited winter rainfall, amount and timing variable.
- Vetch, field pea, bell bean need sufficient fall moisture.
- Trials 2013 – pre-irrigate 2”, dry fall, 6” total rainfall, mostly in Feb-Mar.
- ‘Cucamonga’ California brome and ‘Bracco’ white mustard > 5 t/ac.
- Triticale 4 t/ac, saved soil moisture.



USDA NRCS

*Cucamonga brome and
Bracco white mustard
cover ground in April
- on just 8” moisture*

Cover Crops for Moisture-Limited Regions: Northern Great Plains

- 30% of farmers in Western SARE survey use cover crops for soil health and grazing.
- Water and N use by cover crops can reduce wheat yields if timing is not optimum.
- Recommended practices:
 - Plant in fall or early spring.
 - Terminate at first flower.
 - Winter pea is best.
 - Avoid water hogs like alfalfa.



Black lentil: an excellent rotation cash crop in organic dryland grains.

Doug Crabtree, Vilicus
Farm in Montana

Cover Crops for Moisture-Limited Regions: Northeast Washington State

- 20 farms – NRCS Conservation Innovation Grant
- 11” / yr, mostly winter snow; shallow, stony soils.
- Best results with field pea, spring planting, terminated at 10% bloom.
 - Southern pea, sunn hemp not adapted (summer nights too cool).
 - Bell (fava) bean too drought-susceptible.
 - Hairy vetch and winter rye too weedy in following crops.
- Fall-planting covers were limited by dry soil and weeds.
- Compared to no-cover controls, wheat yields after cover ranged from 34% (severe yield loss) to 122% (significant gain).
 - Yields drop if soil dries to >3 inches at time of grain planting → terminate cover before this happens.

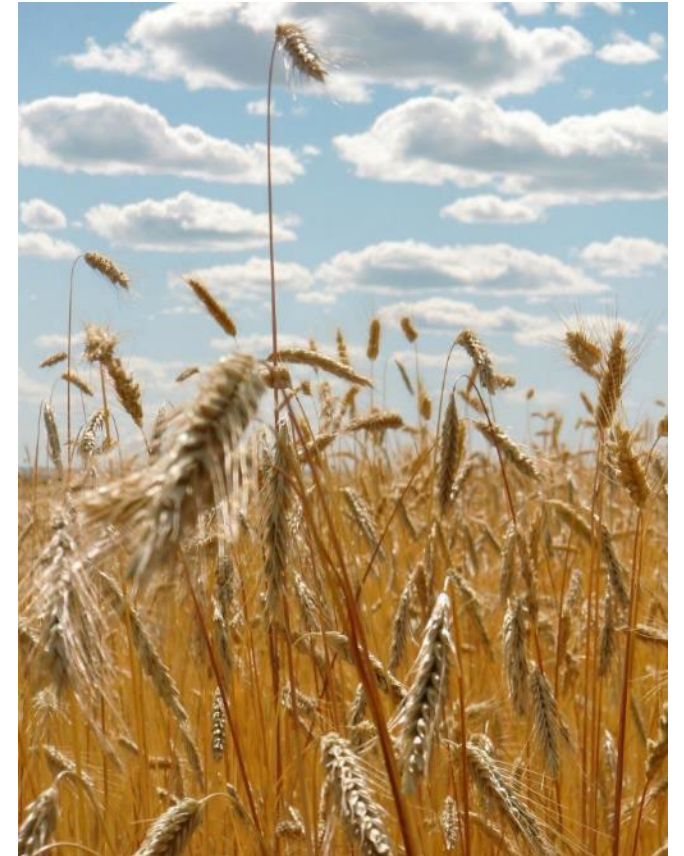
Where It's Too Dry for Year-round Living Cover, Amend with Compost

In organic dryland wheat trials in UT, WA, and MT (Reeve et al., 2021), a one-time application of 22 tons/ac:

- Improved aggregation and water infiltration.
- Enhanced root growth and SOM to 35" depth.
- Greatly increased wheat yields in drought years.
- Benefits have continued for 25+ years.

University of Arizona trials with composted grape pomace + manure (Mpanga et al., 2022) will monitor:

- Soil AWHC and water infiltration
- SOM, soil biology
- Vegetable yield and quality, economic returns



Cereal rye at maturity

Where it's Too Dry for Year-round Living Cover, Protect the Soil Surface with Plant Residues

The blade plow undercuts cover crops and weeds just below surface:

- Leaves residue on surface.
- Leaves most of soil profile undisturbed.
- Saves moisture.
- Reduces wind erosion.
- Improves crop yields over disking.
- Requires just the right soil moisture levels to work well.



The Problem of Winter Fallow in Mediterranean Climates

In central California vegetable growing areas:

- Most rain falls in winter (December - March).
- Crops are grown April – October with irrigation.
- Cover crops are rarely grown.
- Winter rains leach N from fallow fields.
- Ponding degrades soil health.
- Runoff reduces moisture storage for next season.
- Soil erodes from sloping fields.



Zahangir Kabir

Fallow field after a 2" winter rainfall in Woodland, CA

Comparing Runoff from Winter Cover Crop vs Fallow in Field near Davis, CA

50% of
rainfall
runs off



Winter Fallow

Zahangir Kabir



Winter Cover Crop

90% of
rainfall
retained

Salinas Organic Cropping Systems Experiment: Organic Vegetables with Winter Fallow



Spring lettuce



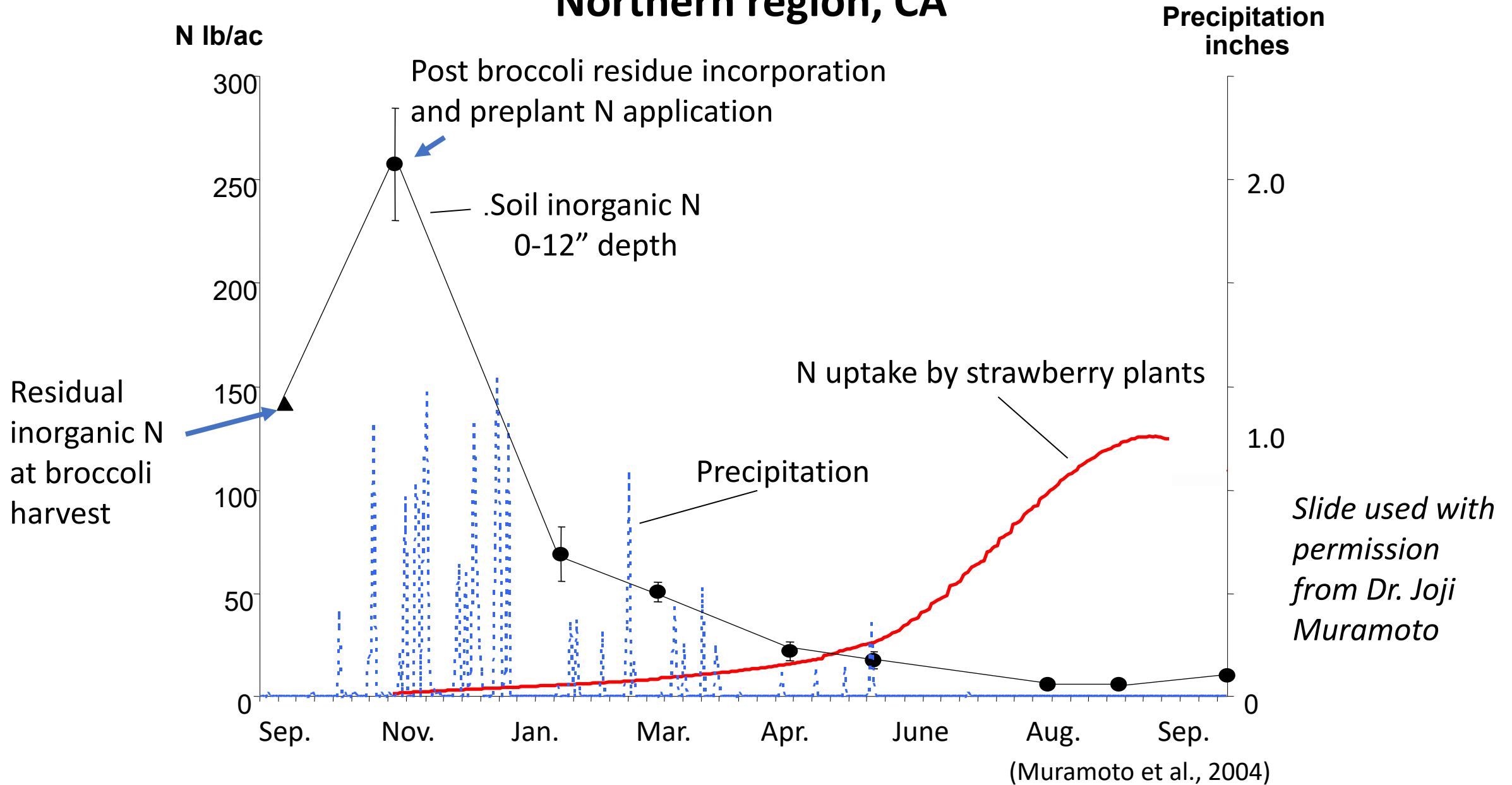
Fall broccoli



Winter Fallow

Leaching, denitrification, compaction

Asynchrony of N supply and N demand in an organic strawberry field in the Northern region, CA



Salinas Organic Cropping Systems Experiment: Organic Vegetables with Winter Cover Crop



Spring lettuce



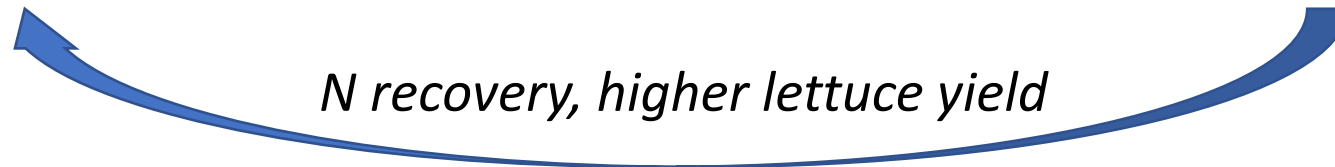
Fall broccoli



Winter cover: rye +
legume mix

Sarah Brown,
Oregon Tilth

N recovery, higher lettuce yield



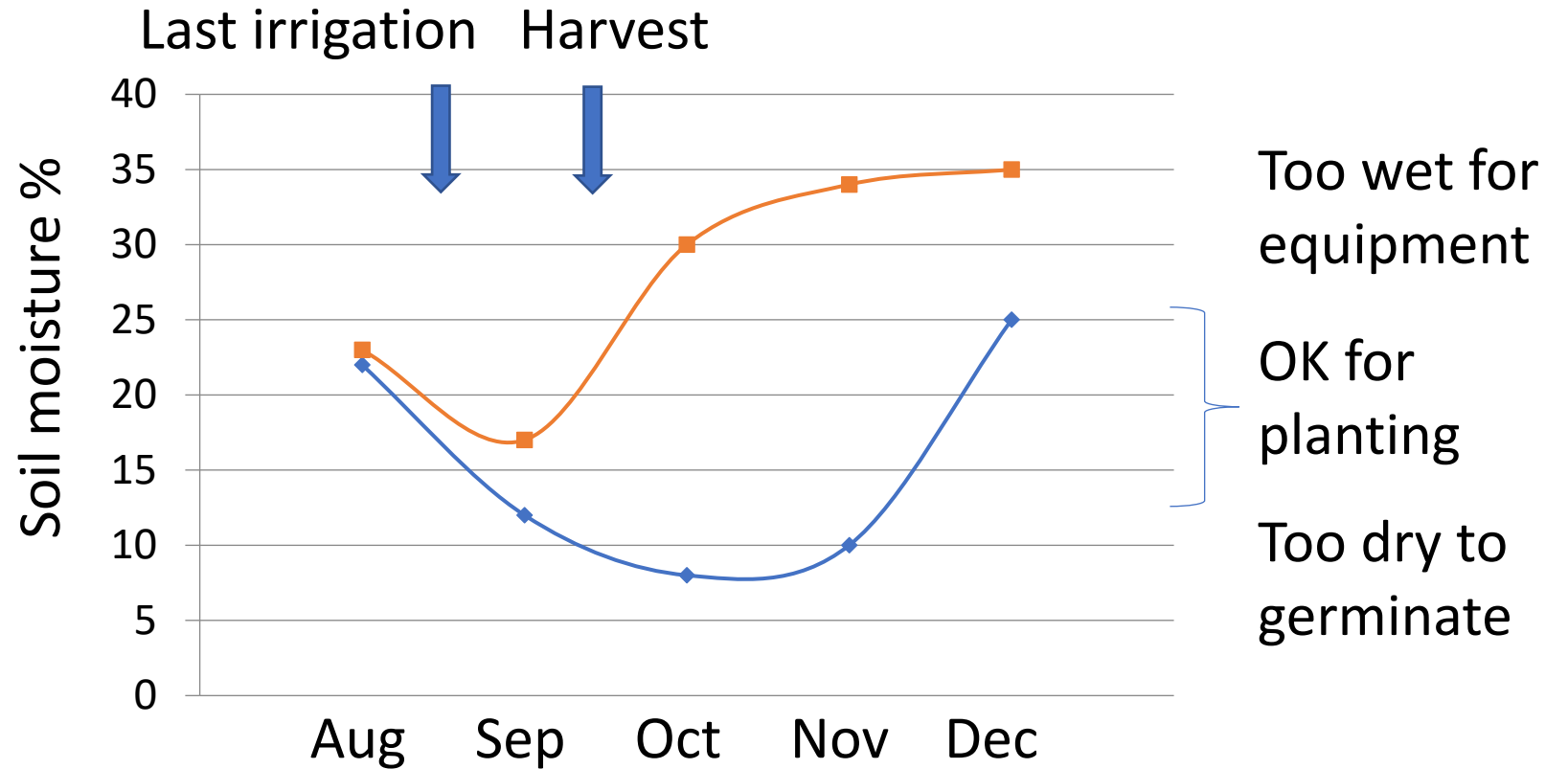
Eric Brennan, USDA ARS,
<https://www.youtube.com/watch?v=JurC4pJ7Lb4>

Getting the Cover Crop Planted: a Timing Challenge

Soil moisture levels in years when winter rains set in:

Early ————

Late ————



Overseeding Cover Crops into Standing Vegetables

Washington
State University



Eric Brennan
USDA-ARS



Nick Andrews Oregon State U,
provided by NCAT/ATTRA.

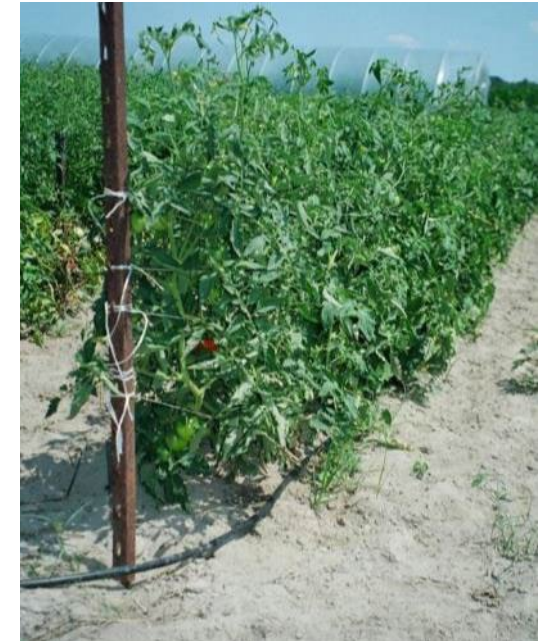
Irrigation Challenges in Organic Production

Water conservation

Soil health

Salinity

Irrigation Methods, Water Conservation, and Soil Fertility



Overhead irrigation (left) loses water to evaporation and can cause surface crusting. In-row drip (center and right) delivers water more efficiently and gently to crops, and reduces between-row weeds, but can also limit soil biological activity and N mineralization between rows.

Irrigation Challenges in Arid Regions

- Soils of arid regions are low in SOM but can become productive if irrigated.
- Using groundwater for irrigation can:
 - Build salts in soil, hurt soil life, degrade tilth.
 - Reduce crop yields.
 - Deplete aquifers.
- Soil health can be difficult to restore in low-rainfall regions.



A saline-sodic soil in a dry climate is prone to further degradation if irrigated for production.

USDA Agricultural
Research Service

Soil Health Practices in Irrigated Organic Orchard in Utah

- Bare orchard floor soils lose SOM and AWHC.
- Legume (trefoil) alleys with mowings blown into rows:
 - Improved tree root growth.
 - Enhanced soil health.
 - Did not affect water needs.
- Organic mulch or low-growing living mulch (*Alyssum*) improves within-row soil health.



Covering orchard floor with living plants enhances crop and soil health without adding to irrigation cost.

Drought Puts Squeeze on California Tomato Growers

- 2014-17 drought sharply reduced irrigation allotments.
- OFRF study: can tomatoes be grown on less water?
- Trials in organic and conventional fields.
- Standard irrigation (until 30 days before harvest) vs deficit irrigation (stop 2 weeks early).



Recently irrigated tomato crop in central California

Healthy Soil Improves Irrigation Efficiency

Park Farming Organics soil health practices:

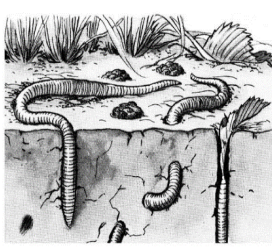
- Diverse crop rotation
- Winter cover crops
- Compost, microbial inoculant
- Reduced till, controlled traffic

Outcomes:

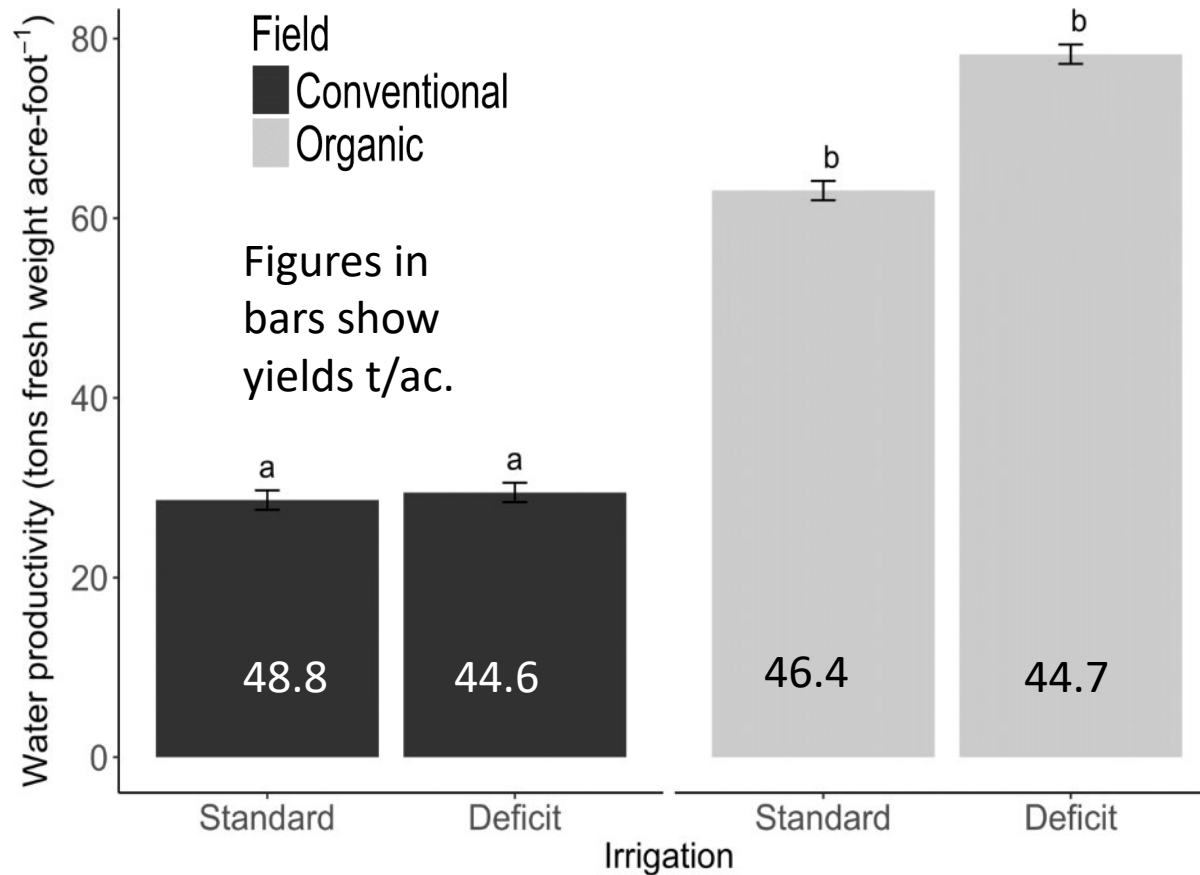
- Nearly 100% of winter rainfall retained in healthy soil.
- Deficit irrigation reduced water use 0.2 – 0.5 acre-ft.



Organic farmer Scott Park cut water use by 6 acre-inches in 2017, yet maintained top tomato yields through soil health practices.



Irrigation water productivity



Organic:

- Much less water used
- Fewer rotten fruit (5% vs 10%)
- Fruit slightly higher in phenols.

Slide by Lauren Snyder, used with permission



Questions?