Organic Soil Health Practices for Water Management and Water Quality

A Webinar for NRCS
June 26, 2023

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Presentation Notes

Slide 2 – *Water is essential.*

Slide 3 – *Water, agricultural production, and soil health*

In addition to direct impacts on production, drought can affect soil health by reducing plant biomass production, resulting is less root exudation to support soil microbes and less canopy or residue cover to protect the soil surface. Vital microbial processes including development and maintenance of stable aggregates as well as formation of soil organic matter (SOM) are slowed or stopped until soil moisture is restored by rainfall or irrigation. Dry, poorly aggregated soil surfaces with inadequate vegetative or residue cover are susceptible to wind erosion losses.

Excessive soil moisture can alter the composition and function of the soil microbial community, leading to increase emissions of the greenhouse gases nitrous oxide (N_2O) when soil moisture exceeds field capacity or methane (CH_4) when soils are completely saturated and ponded (Cai et al., 2016). In addition, excessive rain can leach nutrients from well-drained soils into groundwater, and heavy downpours cause water erosion and nutrient runoff from sloping fields.

Slide 4 – *Irrigation challenges*

Water conservation has become a critical challenge for agriculture throughout the US and especially in the West, where major rivers such as the Colorado have been in danger of drying up due in part to irrigation demands. Irrigation can also affect water quality by transporting nutrients in tailwater or drainage water, and NRCS Conservation Practice Standard 447 Irrigation and Drainage Tailwater Recovery is designed to reduce nutrient losses. Finally, groundwater often contains dissolved salts. When used for irrigation in low rainfall regions or in the high tunnel environment where evapotranspiration exceeds precipitation, the salts in groundwater can lead to salinization of the topsoil.

Slide 5 – *Soil moisture 101* – subtitle slide

Slide 6 – *What happens in soil when it rains*

During a substantial rainfall or irrigation, the soil's pores fill with water from the surface downward. After the rain or irrigation stops, water in the largest pores (gravitational water) drains out, moving down through the soil profile. The amount of water remaining in the soil after the largest pores have drained out is the soil's field capacity (FC). The proportion of FC that is available for plant uptake (capillary water) is the soil's plant-available water holding capacity (AWHC). Water in the smallest micropores (hygroscopic water) is held so tightly that plant roots cannot extract it.

Slide 7 – *Inherent soil properties and water holding capacity*

The first step toward effective water management is to gain an understanding of the soil's inherent (natural) properties, and how these affect the behavior of moisture in the soil profile. Digging a soil pit is a good way to get a close-up view of the soil profile. The NRCS web soil survey provides valuable information on soil texture, drainage, profile, other inherent properties for each soil map unit on a particular farm, plus information on whether erosion from past land management practices has occurred, and other aspects of soil health that may require special attention, including organic matter, susceptibility to compaction and surface sealing, etc. Access the NRCS soil survey at *https://websoilsurvey.nrcs.usda.gov/.*

Slide 8 – *Soil texture, depth to root-restrictive layer, and AWHC*

Medium textured (loam or silt loam) soils have the greatest proportion of capillary pores that hold plant-available water when the soil has drained to field capacity, giving them a higher *plant-available water holding capacity* (AWHC). Coarse-textured (sandy) soils have a larger proportion of macropores that drain out soon after a rain event, and therefore a lower AWHC . Fine-textured (clayey) soils have a greater proportion of very small micropores that hold water so tightly that crop roots cannot extract it, so that AWHC is again limited.

In addition to the AWHC as a percentage of soil volume, total plant-available water depends on how deep plant roots can grow before encountering a restrictive layer. This may consist of bedrock or other parent material (entire soil profile potentially available to plant roots) or a naturally occurring subsurface hard or compacted layer (fragipan, glacial till, etc.), a subsurface hardpan or plowplan related to past management practices, acidic subsoil with phytotoxic levels of soluble aluminum, or a high water table.

For example, if the plant-available water filled pore space at field capacity (FC) comprises 20% of the soil volume, and crop roots can grow to a dept of five feet, the soil can hold 12 inches of crop-available moisture. However, if AWHC is just 15% and crop roots cannot penetrate deeper than 12 inches because of hardpan or other restriction, plant available WHC is only 1.8 inches. Heavier rainfalls will either run off or will percolate to below the crop root zone.

Slide 9 – *Soil profile and plant available water*

Many southeastern US coastal plain soils (primarily Ultisols) have a compaction-prone E horizon below the A horizon (topsoil or plow layer). Warm-season row crops like cotton or soybean often cannot penetrate the compacted E horizon and therefore cannot gain access to moisture and nutrient reserves in the B horizon, which, in Ultisols, is usually finer-textured than the A horizon. Robust, deep-rooted winter cover crops such as cereal rye or tillage radish can penetrate the E horizon, partly because autumn rains moisten the soil profile, thereby decreasing the soil strength (resistance to root growth). Roots of the following cash crop can utilize root channels left by the cover crop to access moisture and nutrients in the B horizon (Marshall et al., 2016).

In the Salinas Valley of California, the Chuluar loam sand is a Mollisol with a strongly clay-enriched B horizon that restricts root growth yet remains sufficiently water-permeable to allow nutrients to leach during the winter rainy season. Winter cover crops can retrieve most of the N left over from summer cash crop production, thereby protecting groundwater quality, and making the N available for the following season's production (Brennan, 2018).

Slide 10 – *Dynamic soil properties and available water holding capacity*

Dynamic soil properties are those that can be altered by management practices such as tillage, organic amendments, and crop rotation, often through the impact of management on soil organisms. For example, winter cover crops sustain mycorrhizal fungi and beneficial bacteria, providing a "green bridge" between preceding and following cash crops. As seen in the past two slides, cover crops and other soil health practices can ameliorate the crop-limiting effects of some inherent properties such as subsurface compacted layers.

Soil structure is modulated in large part by the community of soil life, whose activities continually regenerate soil aggregates and maintain a network of large and small pores. Soil microbes bind soil mineral particles (clay, silt, sand) into porous aggregates with their hyphae (fungi) and carbohydrate "glues" (bacteria). Plant roots, earthworms, and arthropods create an interconnected system of larger pores and channels that, together with the smaller pores maintained by microbial activity, enhance the soil's capacity to hold and deliver plant-available moisture yet remain sufficiently aerated for optimum root function. When the soil surface is protected from sealing and crusting by raindrop impacts and direct sun, pores remain open at the surface to allow rapid infiltration of rainfall, so that more is stored and less runs off.

In addition, both active (partially decomposed) and stable (fully decomposed, adsorbed to silt and clay particles) soil organic matter (SOM) have a large water holding capacity. Although management practices that build SOM and support biological activity will not change the percentages of sand, silt, and clay (soil texture), nor the presence of a clay pan, fragipan, or E horizon, they can significantly enhance the soil's porosity, structure, and AWHC. In a review of multiple studies, Hudson (1994) found that as SOM increased from 0.5% to 3%, soil AWHC more than doubled, and the same trend held for sandy, silt loam, and silty clay loam soils.

Slides 11 – *Water relations in healthy, biologically active soil*

Soils in good health have an open, porous, structure that readily absorbs moisture during rainfall or irrigation, drains sufficiently to regain good aeration soon after the water input, yet retains a large reservoir of capillary water available for plant uptake. Such soils are sometimes described as "spongy," reflecting their capacity to absorb heavy rainfalls, thereby minimizing runoff from sloping fields and waterlogging in level fields. The most fertile and drought-resilient soils also have a deep, open profile allowing unrestricted root growth and affording crops access to deep moisture reserves during dry spells.

Soils need coverage by living vegetation, residues, or organic mulch to protect the surface from raindrop impact and direct sun, which can lead to sealing and crusting of even the healthiest soils. Runoff increases, and the soil's capacity to absorb and store moisture during a heavy rain is reduced. Compaction by tillage, machinery traffic, or overgrazing lwers AWHC and slows infiltration by reducing the total amount of pore space and disrupting connectivity among pores.

Slide 12 – *How healthy soils keep crops watered* – summary, self explanatory

Slide 13 – *Water relations in compacted or crusted soil*

Poor soil management practices, including excessive tillage, overgrazing, extended bare fallow, inadequate living plant cover, over-reliance on soluble or concentrated fertilizers, and insufficient organic material return often leads to compaction (increased bulk density), which reduces plant-available moisture in several ways:

- Surface compaction (sealing or crust formation) closes surface pores, thereby slowing water infiltration, increasing runoff, and reducing the percentage of rain or irrigation water that moves into the soil to meet current or future crop needs.
- Compaction anywhere in the soil profile reduces total pore space, thus less water is retained at field capacity.
- Larger pores are crushed into micropores, so that the soil does not drain well and roots may become oxygen-starved and unable to function normally.
- Collapse of soil pore structure can also increases the amount of hygroscopic (unavailable) water relative to capillary (plant-available) water.
- Roots have a harder time penetrating compacted soil, especially when it is partially dried (below field capacity); thus plants have access to a smaller depth and volume of soil.

Slide 14 – *Water relations in a depleted soil*

Soils that are not compacted but have become SOM-depleted because of inadequate plant cover and organic inputs will also have reduced plant available moisture. While rainfall and irrigation water infiltrate readily into the macropore network, much of it leaches beyond the root zone (carrying soluble nutrients with it), and less remains as plant-available water when the soil is at field capacity. Sandy soils are especially prone to organic matter depletion and are often called "droughty" soils because crops can become stressed within a week or two without rainfall.

Hence, this condition is often a result of both inherent (texture) and dynamic (management related) properties. Good soil management that builds SOM can substantially improve AWHC even in sandy soils (Hudson, 1994; Marshall et al., 2016).

Slide 15 – *Soil management and resilience to drought and deluge*

In the ongoing Rodale farming systems trials in Kutztown, PA (initiated in 1981), organic and conventional systems have given equivalent crop yields overall. In drought years, conventionally grown corn showed visible water deficit stress and early senescence, while organically grown corn remained green and vigorous, and gave 30% higher yields. By 2015, SOM concentration was higher in organic than conventional plots (4.0- vs 3.2%) and visibly SOM-darkened soil color extended deeper into the soil profile (18” vs 10”). Organic soil management improved rainfall infiltration by 15-20%, enhanced AWHC, and could sustain corn yields through drought (Rodale Institute, 2011 and 2015).

Dr. Zahinger Kabir, who took the two almond orchard photographs, says, “Two almond orchard [near Davis, CA] taken in the same day after a rainfall event, only difference is cover crops and no cover. Poor soil structure associated with poor soil health causes the water not to infiltrate.”

Slide 16 – *Climate change – the 21st century monkey wrench for water management and soil health* – subtitle slide

Slide 17 – *How climate change threatens soil health and water supply*

Climate disruptions across the US have led to greater moisture extremes, with extreme droughts in the western US and increased rainfall intensity and total annual rainfall in the eastern and central US. These trends exacerbate the impacts of too little or too much water on soil health.

While total annual rainfalls have increased across the South, rising mean temperatures and sudden weather swings from deluge to hot weather without rain for several weeks have caused severe plant stress and crop yield losses. This phenomenon of “flash drought” can be especially damaging because the preceding period of excessive rainfall reduces crop rooting depth and may compromise root health. When the rain abruptly stops and the soil profile dries out, the crop has little drought resilience nor access to subsoil moisture. The North Central region has also suffered severe droughts (e.g., 2012) as well as floods over the past 20 years.

Similarly, California went through an historic drought during 2014-17, followed by excessive rainfall that adversely affected California and other parts of the Western region in 2018. More extreme droughts followed, culminating in the searing 115 F heat wave of 2021 in the Pacific Northwest. Then, the winter of 2022-2023 brought phenomenal rains and snowpack that reached a depth of 50 feet in parts of the Sierra Nevada (CA) and Wasatch Mountains (UT). This year’s snowmelt poses a serious flooding threat and at the same time could help restore surface and groundwater resources, including the Colorado River, which have been depleted by intensive agriculture and the 22-year megadrought.

Slide 18 – *Extreme rainfall can degrade soil structure*

In Soil Health Benchmark Study conducted by PASA Sustainable Agriculture with over 100 farmers across Pennsylvania using organic or regenerative soil health practices, the record rainfalls of 2018 (150% of normal for the region) substantially degraded soil aggregate stability in both tilled and no-till annual cropping systems (Egan and Nawa, 2021). Although the no-till field crop systems had a very low STIR rating, the persistently wet weather forced farmers to drive on wet soils for planting, spraying, and harvesting operations, and the traffic alone was sufficient to degrade soil structure. In contrast, permanent pasture in grazing operations showed only a slight dip in aggregate stability from the excessive rain. Year-round perennial living roots and fewer field operations that entail driving on wet soil minimized the damage.

Field crop rotations showed a more rapid recovery of soil aggregation during 2019 (a year with normal rainfall totals) than vegetable rotations, possibly because the former average a higher number of days per year under living cover and living roots with associated beneficial microbes.

These findings illustrate the value of perennial cropping systems for resilience to the impacts of excessive rainfall, and the importance of maximizing duration of living cover and living roots and minimizing fallow periods in annual cropping systems.

Slide 19 – *What organic farmers say about water, weeds, and climate*

The Organic Farming Research Foundation (OFRF) conducted a survey of 1,059 certified organic farmers and 71 transitioning-organic farmers and reported findings in its National Organic Research Agenda (NORA) 2022 (Snyder et al., 2022). Survey participants identified climate change as one of several production challenges related to water management. In focus group discussions, farmers noted that weeds become especially problematic in either drought or deluge, and some have had to modify production practices to deal with surplus rainfall.

Regional differences in survey findings reflect both historical climate conditions (low rainfall climates in the Great Plains and interior parts of the Western region) and impacts of climate change over the past 20 years – more rainfall in the East, and less in the West.

Slide 20 – *Farmer adaptation to climate change in the Northeast*

USDA’s regional Climate Hubs provide valuable service in tracking impacts of climate change and developing regional resilience strategies. In the Northeastern region, insurance claims for crop losses most frequently related to drought (38%) or flood (34%), followed by untimely frost or freeze (13%), heat (11%) and hail and other weather impacts (4%).

Although only 10% of New York farmers surveyed after the 2017 floods specifically indicated that they would change practices to reduce erosion, some 70% reported improved resilience to floods from a range of soil health practices already implemented, including cover crops, reduced tillage, and leaving residues on the surface.

The information and perspectives in this slide were presented in a November 27, 2018 webinar by David Wolfe and Alex Hristov of the USDA Northeast Climate Hub.

Slide 21 – *Cover crop confers flood resilience in Floyd County, VA*

This demonstration of the value of cover crops took place in the presenter's home community in Floyd County, VA, during an historic flood in 2015. The sorghum-sudangrass was not killed but bounced back and resumed growth until first frost. Its deep, extensive root system undoubtedly facilitated drainage after the river receded and may have helped soil life to recover from the waterlogging and to attenuate any manure pathogens left by the floodwaters.

Slide 22 – *Climate disruption hits USDA organic research: lessons in resilience*

Organic research funded through the USDA National Institute for Food and Agriculture (NIFA) extramural Organic Research and Extension Initiative (OREI) and Organic Transitions Program (ORG) has felt the impacts of climate change. Of 197 projects awarded between 2015 and 2021, 34 (17%) reported one or more extreme weather events that caused crop failures, destroyed or delayed experiments, or impelled changes in experimental treatments. These events included:

- Drought and heat, often of unprecedented intensity or duration (15 projects)
- Excessive rainfall (15 projects)
- Violent windstorms, tornadoes (9 projects)
- Untimely or unusual freezes, snow, or freezing rain (6 projects)
- Hail (3 projects)

Studies on the long-term soil and crop benefits of compost applications and legume intercrops for organic dryland wheat production in Utah and neighboring states have faced enormous climate-disruption challenges (Reeve et al., 2022). Progress reports in 2021 and 2022 state:

> "*A particularly harsh drought … negatively impacted wheat and intercrop establishment and reduced yields.*"
>
> *"The problems encountered this year were a result of the ongoing 1000-year drought affecting the Intermountain and Pacific Northwest regions. At some locations wheat emergence has been poor resulting in poor competition with weeds. Grower cooperators had to terminate their crops prematurely to prevent weeds from going to seed in large numbers."*

This same study found that a single heavy application (22 tons per acre) of compost made from cattle manure and bedding doubled SOM and crop yields for at least 15 years, with substantial benefits continuing through the 26th year. Soil cores showed enhanced SOM to a depth of 35 inches, likely resulting from greater crop vigor and deeper rooting in wheat and rotation crops grown after the compost application. While the extreme drought in 2020-22 caused some crop failures, compost treatments generally improved wheat yield and soil health parameters.

In a project on diversified rotations for organic cotton production in a semiarid region in Texas, DeLaune (2022) reports compounding impacts of drought and weed pressure:

> *"Due to lingering drought conditions under limited irrigation, wheat failed at the Lubbock location and was not harvested. Similar conditions existed at the Vernon locations but grain was planned for harvest. However, a direct hit from an EF-3 tornado decimated the standing wheat crop just prior to harvest and yield was not collected ... Severe drought continued to hamper each study site.*
>
> *"All crops at the Vernon site were re-planted due to extreme weed pressure.*
> *"Even with hand weeding, another flush of pigweed was observed at Vernon."*
>
> *"Crops planted in year 2 of the crop rotation included peanuts, sesame, cotton, and hay after wheat ... At Lubbock, continuous cotton treatments had lower stored soil water compared to crop rotation treatments. Crop rotation and diversity has the potential to improve soil function (e.g. increased soil water storage)"*

Intense weed competition played a role in crop failures resulting from unprecedented drought in several other OREI-funded projects. Yet, in one project to develop organic IPM strategies against two creeping perennial weeds, Canada thistle and field bindweed, even the target weeds had a hard time in the historic 2021 drought in the Pacific Northwest (Carr et al., 2022):

> *"A second study looking at impact of previous treatment effects on field bindweed control in vegetable crops was ... reestablished at Corvallis in 2022 because thistle and bindweed ramets planted when the study began failed to persist because of severe drought in 2021."*

Slide 23 – *Managing water quantity and quality in organic farming systems* – subtitle slide

Slide 24 – *Water conservation in organic farming*

Several questions in the OFRF farmer survey (Snyder et al., 2022) focused on water conservation and other practices that can have positive impacts on the soil's capacity to store and deliver crop-available moisture and to protect water quality by retaining nutrients. The slide shows the percentages of farmers who reported implementing these practices "often" or "very often."

Water conservation practices include "implementing drip irrigation, adapting irrigation scheduling to current weather conditions, growing drought tolerant crops, mulching, etc." (Snyder et al., 2022, page 48). These practices were especially important in the western US and for specialty crops (vegetables, berries, tree fruits and nuts) across the US.

Slide 25 – *NRCS soil health principles, soil water, and organic practices*

The National Organic Standards require soil health management practices that build and maintain the "physical, chemical, and biological condition of soil" including SOM These practices also improve plant-available water holding capacity and the farm's resilience to drought and excessive rainfalls. Most of these practices also help protect water quality.

As noted earlier, healthy, living soil holds more crop-available water. Diversified crop rotations that include species with deep and shallow roots and contrasting rooting architectures optimize soil water relations by building SOM and pore networks throughout the soil profile Combining or alternating deep and shallow rooted crops can also enhance water use efficiency by balancing crop water demands near and below the surface and throughout the season.

Slide 26 – *Cover crops and soil water*

Cover crops play a central role in effective water management in organic annual cropping systems. They enhance soil water relations by protecting the soil surface, by creating pores and channels as deep as their root systems extend, and by feeding soil life.

While cover crops provide these benefits, they also consume soil moisture while they are growing. This can be advantageous when wet conditions might otherwise complicate cash crop planting – and raises legitimate concerns for crop production in rainfall-limited regions. Cover crop management strategies for regions with different rainfall regions will be discussed later.

In moderate to high rainfall regions, cover crops should be grown to maturity (full head / bloom) to realize maximum long-term benefits to SOM, soil structure, and water holding capacity. The triticale + Austrian winter field pea shown here was planted in early fall and photographed at the end of May in Blacksburg, VA. At this time, it contained about 5 tons aboveground biomass per acre, plus 2 – 3 tons below ground including root biomass and root exudates. The dense cover also protects the surface from crusting and erosion, even in the event of a heavy storm.

Slide 27 – *Rye cover crop enhances soil moisture and cotton yields*

In these trials in on sandy Ultisols in the coastal plain of South Carolina, soil moisture content during fall and winter was sufficient to allow the deep, robust, fibrous root system of a cereal rye cover crop to penetrate the E horizon. This opened channels for the following season's cotton crop to access the moisture and nutrient reserves of the underlying, clay-enriched Bt horizon. In addition, the rye cover crop increased soil organic matter from about 0.9% to 1.4%, and season long soil moisture measurements at 6, 12, and 18 inches indicated that the rye cover crop enhanced volumetric soil moisture by 6.2% (~1.1" moisture in top 18 in) and 8.5% (~1.5") in Fuquay loamy sand and Faceville sandy loam soils, respectively. With this enhanced AWHC and access to a greater depth of the soil profile, no-till cotton yields were substantially improved (Marshall et al., 2016).

On an *extremely* sandy soil (Lakeland sand), low cover crop biomass (500 lb/ac vs 2200 and 5000 lb/ac in Fuquay and Faceville, respectively), resulted in reduced cover crop benefits.

Radish has even greater subsoiling capacity than rye but was winterkilled in these trials by unusually intense winter freezes.

Slide 28 – *Mulching and soil water*

Organic mulches such as straw or hay act like a one-way valve, absorbing rainfall while curbing evaporative losses and hindering emergence of weed seedlings (thereby reducing competition for moisture). They also add organic matter, feed soil life, and protect the surface from raindrop impact and crusting. In a mulching systems study for organic tomato in Virginia, hay mulch enhanced plant-available moisture in the top 12 inches by 0.6 to 1.0 inch in two out of four site-years (Schonbeck and Evanylo, 1998).

Synthetic (plastic) mulches are widely used to maintain higher soil temperatures, conserve moisture, prevent fruit rot and stop weed growth and competition in organic strawberry and vegetable production. However, they also block rain and overhead irrigation, and thus require drip irrigation tape laid under the film in order to deliver water to crops. Runoff from the nonporous film during natural rainfall can erode soil from alleys in sloping fields, and cause alley puddling in level fields. The runoff reduces rainfall recharge of in-field soil moisture (increasing future need for irrigation) and can carry off nutrients and soil.

In central California, both organic and conventional strawberry are typically planted in November in plastic mulched raised beds. Most of the region's ~15 inches annual rainfall takes place during December-March, and even a moderate rain event (0.4 inch) runs off the plastic beds into furrows, where the excess water ponds, causes nitrate-N leaching and denitrification, and soil erosion and additional nutrient losses through runoff.

Weed mat (= landscape fabric) allows rain or overhead irrigation water to enter the soil profile and maintains excellent weed control. It is not as rapidly permeable as organic mulches, and heavy rain can run off or pond temporarily. Unlike film, it can be reused for many seasons.

Slide 29 – *Compost, manure, and soil water*

Organic amendments, especially finished compost, play an important complementary role with living plant roots in building SOM and hence moisture holding capacity. Several studies have found greater SOM accrual with cover crop + compost or manure than with either practice alone (Hooks et al., 2015; Hurisso et al., 2016).

Judicious use of manure and other concentrated organic nutrient sources such as pelleted poultry litter fertilizer can benefit water management by optimizing cover and cash crop growth, resulting in more organic matter input to the soil and higher yield per inch of moisture used.

The efficacy of organic soil amendments in building active and total SOM is greatest for finished compost with a balanced C:N ratio (15 – 20:1), followed by solid livestock manure with bedding, then poultry litter, then manure slurry or digestate from anaerobic digesters for methane capture from liquid manure (National Sustainable Agriculture Coalition, 2019). In a long term (11 year) organic vegetable systems trial, plots receiving finished compost (C:N ~ 20) for N had 30% more SOM than poultry litter (C:N ~7) at equivalent N rates (Bhowmik et al., 2017). Other long-term systems trials have shown that integrated organic systems (compost, cover crops, and diverse rotation) can build SOM, AWHC, and permeability (Cavigelli et al., 2013; Delate et al., 2015).

Smaller scale organic producers who must make a living on limited acreage and plant multiple production crops per year (thus, fewer or no cover crops) commonly use large amounts of compost to build soil health and fertility. While the compost adds stable SOM, it can build excess soil P, which inhibits arbuscular mycorrhizal fungi (AMF). AMF play a vital role in moisture uptake efficacy and drought resilience in grains, legumes, and many vegetable crops.

Slide 30 – *Reducing tillage to conserve soil water holding capacity*

In the Pacific Northwest, primary tillage with a spading machine versus plow-disk consistently reduced soil compaction, and sometimes improved vegetable yields (Cogger et al., 2013). Virginia grower Rick Felker (Mattawoman Creek Farms) reduced the impact of rototilling on soil structure simply by lowering rotary speed and increasing tractor forward speed (Schonbeck et al., 2017). Terminating a cover crop with the sweep plow undercutter (= blade plow) leaves much of the residue on the surface and most of the root mass undisturbed in the soil profile. In a Nebraska study, terminating cover crops with the sweep plow undercutter conserved soil moisture and enhanced corn and soybean yields by 17 and 23% compared to a no-cover control, while the same cover crops terminated by disk increased soil moisture losses and cut soybean yields by 14% compared to the control (Wortman et al, 2016).

Slide 31 – *Reducing cultivation frequency with ecological weed IPM*

Effective weed control is important for ensuring sufficient soil moisture for crops. Organic farmers sometimes face a difficult tradeoff between the soil health costs of tillage and cultivation and potential crop losses to excessive weed competition.

Shallow cultivation leaves most of the soil profile undisturbed, and if done when weeds are just emerging or less than two inches tall, can be highly effective. However, repeated cultivation to maintain weed control can pulverize the soil surface and thereby promote surface sealing after rainfall or overhead irrigation. This in turn, can reduce moisture infiltration into the soil profile.

Integrated weed management that includes multiple tactics can reduce the number of cultivations needed, especially when alternative tactics such as mowing, mulching, grazing, and/or thermal (flame, steam, hot water) weeding are implemented. Strategic crop rotations and weed-suppressive cover crops can further reduce the need for cultivation.

Slide 32 – *Livestock grazing and soil moisture*

Management intensive rotational grazing (MIG), in which each paddock is grazed intensively for 0.5 to 3 days, then allowed to recover fully (30-90 days depending on climate, season, etc) fosters deep, extensive root systems that support vigorous, diverse, drought-resilient forage. Manure deposition and root sloughing after the grazing shock build SOM, pore space, and AWHC throughout the soil profile. Rancher Gabe Brown (2018) has restored 5,000 acres of cropland and grassland at his North Dakota ranch by implementing the NRCS four soil health principles and integrating rotationally grazed livestock. Over a 20-year period, SOM increased from less than 2 percent to more than 6 percent, and Brown estimates that soil AWHC has increased by about four-acre-inches (100,000 gallons/ac) as a result.

Multiple studies in humid and semiarid regions show that MIG systems can restore grassland soils to near native SOM levels, which improve AWHC, forage quality, and drought tolerance (National Sustainable Agriculture Coalition, 2019; The Natural Farmer, 2014-15, 2016-17). More recent studies of MIG versus continuous grazing have given mixed results, possibly because research protocols included a formulaic rather than adaptive approach to grazing schedules. Climate change may make an adaptive approach both more essential and more challenging in practice.

Slide 33 – *USDA National Organic Standards on water resources*
Slide 34 – *Water quality in organic farming*

In addition to facilitating development of diverse beneficial soil biota that contribute to soil permeability and AWHC, careful nutrient management that avoids excessive levels of soluble N and P in the soil protects water quality. High levels of soluble N maintained over long periods can cause a net loss of SOM, as well as reducing depth and extent of plant root systems, thereby compromising crop drought resilience and nutrient recovery. Organic production systems that use slower-release organic and natural mineral nutrient sources generally maintain lower soluble nutrient levels and thereby minimize nutrient losses while creating more hospitable conditions for beneficial soil organisms.

Slide 35 – *Water quality concerns in different rainfall regimes*

In higher-rainfall climates across the eastern half of the US, annual precipitation exceeds annual evapotranspiration. Water quality concerns include leaching or runoff of surplus nutrients.

Soils in Mediterranean climates such as the Pacific Coast states, can be prone to leaching during winter rainy seasons, yet have substantial moisture deficits and require irrigation for production during rainless summers. Substantial wintertime leaching of leftover N can occur in both organic and conventional systems. Winter cover crops can retrieve much of the N and reduce fertilizer N needs for the next crop (Brennan, 2018; Muramoto et al., 2015; Wyland, 1996).

In low-rainfall climates, annual evapotranspiration exceeds annual precipitation, so that a net upward movement of moisture through the soil profile can occur, resulting in accumulation of dissolved salts near the surface. At Vilicus Farms in Havre, MT (average annual precipitation 11.7") Doug and Anna Crabtree implement integrated sustainable organic practices including diversified rotations that include more than 20 regionally adapted cover and cash crops, crop-livestock integration, and perennial conservation buffer plantings (shown in the photo) over 25% of their acreage. Their system has enhanced soil health and avoided salinity problems.

Slide 36 – *Cover crops and soil water in challenging climates* – Subtitle slide

Slide 37 – *Dryland challenge*

In low-rainfall regions, dryland organic wheat producers face a difficult tradeoff between the known benefits of cover crops and the soil moisture consumed by the growing cover crop.

In dry regions, cash crops and cover crops in the rotation vie with one another – and with weeds – for limited moisture. As a result, it is more difficult to grow a cover crop to sufficient biomass to control erosion and build organic matter and water holding capacity. If the cover crop does attain high biomass, it may also consume so much moisture that grain yields become severely water-limited. Terminating the cover crop by tillage can further compromise benefits, as semiarid regions soils are especially prone to wind erosion, SOM loss, and reduced fertility. Organic no-till termination is often complicated by perennial weeds. Yet, not growing a cover crop can further reduce SOM, and fertility, aggravate erosion, and reduce long term AWHC.

In semiarid regions, the traditional two-year cereal grain / fallow rotation is used to store two years' worth of moisture for the cash crop, but multiple studies have shown that the prolonged fallow degrades SOM and water holding capacity, even in no-till systems (Halvorson et al., 2002; West and Post, 2002). Diversifying the rotation with pulse, oilseed, and/or cover crops during the fallow year improves soil health and AWHC yet can reduce yields of the next crop by consuming moisture (Halvorsen et al., 2002; Lehnhoff et al., 2017; Menalled et al., 2012).

Care is needed in selecting the cover crop, planting and termination dates in order to minimize impacts on moisture available to the following crop (Menalled et al., 2012). Doug and Anna Jones Crabtree of Vilicus Farms in Havre, MT (https://www.vilicusfarms.com/) have developed a diversified 7-year rotation of cereal grains, pulses, oilseeds, and green fallow (cover) crops that sustains soil health and crop yields in a region that averages 11.7 inches of moisture per year. Strategic and adaptive timing of cover crop planting and termination aims to optimize biomass and N while conserving soil moisture for the next crop.

Slides 38 and 39 – *Cover crops for semiarid climates*

Cover crops for dryland grain rotations must combine water use efficiency, drought resilience, and sufficient biomass and N fixation (legumes) for significant benefits. Winter-planted field peas have yielded significant benefits (N, weed suppression, long term soil health) with minimal moisture-related drawbacks (Gallagher et al., 2006; Miller et al., 2009). Pearl millet has performed well as a cover crop in New Mexico (USDA SARE, 2007).

Plants can be drought resilient because they use water efficiently, needing less moisture to achieve desired biomass, coverage, and yield, or because they have deep, extensive root systems that can tap subsurface soil moisture reserves. Dryland farmers need cover crops that combine high drought tolerance with low water use intensity. Examples include barley, foxtail and pearl millets, field pea, lentil, lupin, southern pea (= cowpea), medic, and amaranth (USDA, 2023).

In contrast, the drought resilience of alfalfa, sunflower, safflower, and sainfoin is based largely on their capacity to tap – and often deplete – moisture reserves throughout the entire soil profile. For example, alfalfa typically extends roots to 6 to 10 feet, and sometimes as deep as 30 to 40 feet. Montana State U researchers report that crops grown for the first year or two after alfalfa sod is broken can suffer moisture deficits and give lower yields compared to crops grown after less moisture-demanding covers or fallow (Menalled et al., 2012). In contrast, pearl millet and southern pea combine deep roots with light moisture demands.

The examples on this slide are based on the Cover Crop Chart developed by USDA Agricultural Research Service (ARS) Northern Great Plains Research Laboratory in Mandan, ND (USDA, 2023), a New Mexico Extension publication (Idowu and Grover, 2014), the SARE cover crop manual (USDA SARE, 2007), and personal experience with some of the cover crops.

Slide 40 – *Cover crops for moisture-limited regions: California Central Valley*

Researchers at the Plant Materials Center (PMC) in Lockeford, CA conducted field trials to evaluate winter cover crops for drought tolerance. Soil was pre-irrigated (2 inches) in October, cover crops (single species and mixtures) were planted on November 26, 2013 and grown with no further irrigation. Rain totaled 6.08", with 0.43" in Dec, none in Jan, 5.65" during Feb-Mar.

Dry weight biomass at termination approached 11,000 lb/ac for Cucamonga brome (*Bromus carinatus*), Bracco mustard (*Sinapis alba*), brome + mustard, and triticale + mustard (with virtually no weeds), 8,000 for triticale, 4,700 for 'Blando' brome (*Bromus hordaceous*), and 1,500 lb/ac plus 3,368 lb weeds/ac for spineless burr medic (*Medicago polymorpha*) which germinated poorly (Smither-Kopperl and Alvarez, undated). Soil moisture levels in April were highest in the triticale treatment.

Trials were repeated the following winter. Heavy rains in December delayed planting until late January 2015, and cover crops were grown without irrigation until early May (105 days). Extreme drought during this period (total rainfall 2.83") reduced triticale and Cucamonga brome biomass while Bracco mustard and hairy vetch showed remarkable resilience with a rapid increase in percent ground cover in April and May (Smither-Kopperl and Borum, undated).

These findings exemplify the region-specific nature of cover crop performance and species selection for best outcomes. The USDA Cover Crop Chart rates triticale as "high water use," yet, in the 2013-14 trial, the triticale plots held more soil moisture as of April (near the end of the cover crop growth period) than any of the other cover crops, indicating that "triticale was particularly effective in increasing water infiltration after precipitation events." This observation and the outstanding performance of the Cucamonga brome, Bracco mustard, and hairy vetch in these trials may be specific to the soils and climates of central California.

Slide 41 – *Cover crops for moisture-limited regions: Northern Great Plains*

Montana State University researchers and farmers have investigated the benefits and drawbacks of cover crops. In a survey of 161 Montana farmers (Western SARE project SW11-099), about 30% reported using cover crops; most intend to continue doing so because they have observed benefits to soil health, and half use the cover crop for grazing as well. Moisture use by the cover crop is a concern, as confirmed in on-farm trials (Jones et al., 2015).

Montana State University Extension bulletins emphasize that cover crops, green manures, and legume cash crops (lentils, peas, other pulses) are foundational to soil fertility in organic dryland rotations. Cover crop benefits include legume-fixed N, possibly increased P availability, reduced fertilizer bills, and a "rotation" effect (better grain yields in diversified rotation) as well as long term improvements in SOM and soil health (Menalled et al., 2012; Olsen et al., 2010).

Planting promptly in fall after grain harvest gives better weed control and biomass than spring planting. Terminating early enough (bud to bloom stage) can reduce moisture deficit / yield tradeoff for the following grain. Terminating later (pod set) increases moisture use yet increases long term SOM, organic N, and soil health benefits. Winter pea can be killed by roller-crimper at pod stage but not the bloom stage, and no-till termination may help conserve moisture.

Fall planted winter pea outperformed other legumes (lentil) and spring-planted pea for biomass, N fixation, moisture efficiency, timely termination, and subsequent grain yields (37 vs 26 bu/ac for winter wheat after winter vs spring pea (Olsen et al., 2010). OREI has recently funded University of Idaho to conduct additional research into winter pea intercrops in organic dryland cereal grains (Liang et al., 2022). Initial results indicate that barley-pea intercrops offer higher biomass and greater weed suppression than wheat monoculture or wheat-pea intercrops.

Eight farms tested various mixes, such as camelina, flax, oat, pea, radish, turnip, and vetch; or buckwheat, camelina, berseem clover, pea, safflower, and turnip. Cover crops were planted April – June and terminated June – September (~40 -90 DAP). Biomass was 900 – 2600 lb/ac, with little weed biomass. However, compared to herbicide fallow, the cover crops depleted soil moisture (at surface to 36 inches) by 2.9 (range 0.7-5.3) inches, and soil nitrate-N by 54 (22-86) lb/ac; and reduced yields by an average of 17.4 bu/ac or 25% (3 to 58%) (Miller, 2016).

Research station trials that were planted and terminated earlier (~April 1 / July 15) in six site-years generated higher biomass (1500 – 4000 lb/ac), consumed less soil moisture (1.8 inches), and caused moderate (9.4 bu/ac) yield losses at one site (northern MT) and no loss at a second site with better winter moisture recharge (Gallatin Valley) (Miller, 2016).

Slide 42 – *Cover crops for moisture-limited regions: northeast Washington State*

Twenty dryland wheat farmers in northeast Washington participated with the Okanogan Conservation District in a NRCS Conservation Innovation Grant (CIG) to adapt the Four Principles of Soil Health Management to their region, which poses unique challenges (Michel, 2018). Many of the farms have shallow, stony soils, and most of the year's limited moisture (average 11 inches) comes in the winter as snow, so that summers are extremely dry. In contrast, the Northern Great Plains receive a similar amount of moisture more evenly distributed through the year (Montana) or mainly in summer (Dakotas), and the inherent properties of many of the soils are more favorable (order Mollisols). Thus, northeast Washington growers may need to use different cover crops, planting and termination dates, and management practices from Northern Great Plains farmers working with similar total annual moisture.

Participants conducted four years of trials in which various cover crops were grown during the fallow year in a wheat/fallow system. Wheat was planted about August 20 and harvested the following July or August followed by 12-13-month fallow.

In the control (standard practice), fallow was maintained by herbicides or by tillage every 6-8 weeks. Cover crop treatments included:

- Fall cover: pea, lentil, barley, triticale, and radish, planted late September and terminated in mid-April.
- Spring: pea, lentil, oats, triticale, and turnip, planted in April, terminated July 1
- Summer: millet, sorghum, radish, sunflower, and pea, planted May 15 (frost free date), terminated July 10.

In initial trials, southern pea and sunn hemp, known for their heat and drought tolerance and strong performance across the South, did not do well in the eastern Washington trials, possibly because nights were too cool and soil moisture was inadequate. Field pea did well in all three planting dates, while fava bean suffered from lack of moisture. Both winter rye and hairy vetch were found to be too likely to become weeds in subsequent crops (Michel, 2018).

Fall planted covers were often planted in dry soil and lay dormant until spring while weeds got a head start. Spring planted covers established promptly on winter moisture and kept weeds down.

When cover crops were seeded at the 30 – 40 seeds per square foot recommended by NRCS, the stand was too dense and plants competed with one another for moisture and nitrogen, turning yellow and ceasing growth when small. Lighter seeding rates based on annual precipitation gave better stands. The team used the formula of 12 seeds per square foot for 10" annual precipitation, add another seed per square foot for each additional inch of moisture.

Wheat yield after the cover crop averaged 85-90% of control but varied from severe losses (as low as 34% of control) in a few trials to measurable yield increases (102 – 122% of control) in about a quarter of trials. The yield response to cover crop reflected depth to moisture (DtM). Drills can set wheat seed about 3-4 inches deep; thus soil drying that goes any deeper interferes with germination and establishment. Taking soil cores during cover crop growth to monitor soil moisture can inform the farmer when it is time to terminate the cover crop.

Surprisingly, the summer cover crop (terminated four weeks before wheat planting) did not necessarily cause the greatest drying or poorest yield outcomes.

Slide 43 – *When it's too dry for year-round living cover, amend with compost*

Ongoing studies at Utah State University have documented multiple benefits of a single, large application (22 tons/ac) of a finished compost derived from cattle manure and bedding in organic dryland grain production in MT, UT, WA, and WY. These include substantial increases in SOM and wheat yields, greater crop resilience to drought, improved soil physical properties and water infiltration, and increases in soil carbon fractions from surface to 35" depth, likely a result of enhanced root growth in compost treatments (Reeve et al., 2022).

Yields in 2020-22 responded to one-time compost applications in 2015 or 2019, confirming a long-term legacy effect, and soil aggregate stability was highest for the 2015 application, suggesting that aggregates build gradually over multiple years after the compost application. In the historic drought and heat of 2021, the high compost rate (22 tons/ac) nearly doubled crop yields over the urea-fertilized control treatment.

Because a single compost application yields these benefits for at least 25 years, this strategy avoids the high costs and risks of excess P buildup associated with annual applications. University of Arizona researchers are exploring the value of grape pomace, which the state's wine industry currently disposes in landfills, as a resource to improve the health and moderate the pH of the region's alkaline, low-fertility soils. They are composting the acidic grape pomace with poultry manure or horse manure (70:30 pomace:manure), will apply the amendments at 250 lb total N per acre, and then monitor impacts on soil health parameters including AWHC and water permeability, crop yield and nutrient contents, and net returns (Mpanga et al., 2022).

Slide 44 – *When it's too dry for year-round living cover, terminate cover crops with a blade plow*

The blade plow, noble plow, or sweep plow undercutter, is a valuable tillage tool for organic dryland production in regions with limited rainfall. The photos were taken from a U. Nebraska Lincoln article on stubble mulch tillage at https://cropwatch.unl.edu/tillage/stubble.

In Nebraska, an early spring cover crop of legumes + mustard terminated by blade plow conserved moisture, reduced weeds, and improved yields of soybean (23%) and corn (17%) compared to a no-cover control, while the same cover crop terminated by disking promoted soil moisture loss and reduced soybean yields by 14% (Wortman et al., 2016).

In the Columbia plateau (annual precipitation <12"), managing wheat stubble and weeds during the summer fallow period with the blade plow significantly reduced wind erosion, compared to disking. The trials were done on silt loam soils with 1% SOM (Sharratt and Feng, 2009).

Slide 45 – *The problem of winter fallow in Mediterranean climates*

With mild summer temperatures near the coast, available water from mountain snow melt to irrigate summer crops, and winters too wet to work the soil easily, most crop production in coastal California and the maritime Pacific Northwest takes place from mid-spring through late autumn, usually with irrigation. This seasonal pattern leaves fields fallow and subject to soil degradation during the rainy winter season.

Slide 46 – *Comparing runoff from winter cover crop versus fallow in field near Davis, CA*

Dr. Zahangir Kabir, NRCS Soil Health Specialist at Davis, CA, compared runoff from a cover cropped versus a bare fallow field during winter. Using equipment to obtain continuous real-time measurements of runoff during rain events, he found that the cover cropped field retained 90% of the winter's rainfall while the fallow field lost nearly half of the rainfall in runoff.

Slide 47 – *Salinas Organic Cropping Systems Experiment: organic vegetables with winter fallow*

In the maritime Mediterranean climates of California and the Pacific Northwest, summer crop production followed by winter fallow commonly results in substantial leaching of nitrate-N with the net downward movement of water from winter rains. In an eight-year organic vegetable systems trial conducted in the Salinas Valley of California by Dr. Eric Brennan of USDA Agricultural Research Service (Salinas Organic Cropping Systems Experiment), a double cropping system of spring lettuce followed by fall broccoli was managed with vs. without cover crop, and with vs. without compost applications (Brennan, 2018; Brennan and Acosta-Martinez, 2017). The trial was conducted on a Chualar loamy sand, which is well drained but has dense, root-restrictive clay horizon about 30 inches below the surface.

Broccoli is a very heavy N feeder and receives 145 lb N/ac from organic sources in this trial, but broccoli harvest removes only about 25% of this N. In the winter fallow treatment, depicted in the slide, the leftover N, winter rains leach the leftover N out of the root zone.

Slide 48 – *Asynchrony of N supply and N demand in an organic strawberry field in the northern region of California*

In an organic broccoli-strawberry rotation in northern California, nearly 150 lb inorganic N/ac remained within the top foot of soil at broccoli harvest (September), increasing to 260 lb/ac after incorporation of broccoli residues, application of organic NPK fertilizer, and strawberry planting in November. The goal was to utilize leftover broccoli N to meet part of the strawberry crop's nutrient needs; however, winter rains leached nearly 90% of this N from the top foot before the strawberry crop began to consume significant amounts of N in April (Gaskell et al., 2009; Muramoto et al., 2015). This slide is taken from a 2015 webinar with permission from Dr. Joji Muramoto of University of California at Santa Cruz.

Slide 49 – *Organic vegetables with winter cover crop*

While strawberries planted after broccoli cannot utilize the leftover N, vigorous, deeper-rooted winter cover crops can do so quite effectively. In the Salinas Organic Cropping Systems Experiment, lettuce gave high yields (1000 boxes/ac, about 30 lb/box) only when a winter cover crop was grown prior to the lettuce. In rotations where the field was left fallow over winter, lettuce yields declined sharply to a few hundred boxes per acre, and sometimes to a total crop failure (Brennan, 2018). While compost applications substantially increased SOM and soil test P, they did not sustain lettuce yields without the winter cover crop. Cover crops of rye alone, mustard, or rye with vetch, fava bean, and pea were similarly effective, indicating that the cover crops supported lettuce N nutrition and yield, not through N fixation, but by recovering the 100+ lb N/ac left over from the preceding fall broccoli crop, and making it available to the lettuce.

In an earlier study on the Chuluar loamy sand in the Salinas Valley, winter rains leached some 230 lb nitrate-N/ac from a bare fallow soil profile after harvest of heavily fertilized conventionally grown vegetables. November-planted cover crops of cereal rye or phacelia attained ~3,200 lb/ac biomass by the termination date (March 20), and reduced N leaching by 65 - 70%, partly through N uptake and partly by reducing downward movement of water by about 38% (Wyland et al., 1996).

Slide 50 – *Getting the cover crop planted: a timing challenge*

Depending on locale, season and the timing of cash crop harvest relative to the onset of winter rains, cover crop planting and establishment can be complicated either by dry or by excessively wet soil conditions. Growth of cover crops planted late in the fall can also be limited by freezing temperatures in northern or inland locations.

Slide 51 – *Overseeding cover crops into standing vegetable crops*

Overseeding cover crops into standing cash crops can be an important strategy for overcoming the challenges of cover crop establishment in a dry summer / rainy winter regime. Several examples are shown here including (clockwise from top left) legume cover crops planted between rows of kale (at mid-growth) in western Washington, oats in eggplant (post-harvest – frost-killed stalks remaining) and red clover in butternut squash (harvest-ready) in western Oregon, and 'Ida Gold' mustard planted in furrows between plastic mulched strawberry beds in the Salinas Valley of California.

In the first three examples, the cover crop was relay-planted into a growing cash crop, at a time when both crops could be irrigated as needed. After vegetable harvest, the cover crop continues to grow through the rainy season, protecting the soil surface, reducing runoff, and utilizing moisture and nutrients that would otherwise be lost to leaching.

In the fourth, the mustard helps intercept rain runoff from the plastic mulched strawberry beds and reduces nutrient and sediment losses from the field. The mustard recovered about 22 lb N/ac and was easily killed with a weed whacker in February just before it grew tall enough to begin shading the strawberry crop (Brennan et al., 2018).

Overall commentary on the findings summarized in Slides 40 and 45-51

These cover crop overseeding successes, combined with the remarkable performance of several winter cover crops on limited rainfall (Smither-Kopperl, M. and S. Alvarez, Smither-Kopperl and Borum), and the vital role of winter cover crops in N recovery (Brennan, 2018) provide solid science to support widespread implementation of cover cropping in the Central Valley of California and throughout the Pacific coast region. As climate change intensifies water-related challenges in this region, cover cropping will play a critical role in water conservation, water quality, and agricultural resilience to climate change.

The following steps can help overcome barriers to adoption:

- Additional research and development of cover cropping practices for this region and the prevailing cropping systems, possibly including development of new or modified tools and equipment for cover crop planting, interplanting, and termination.
- Farm field days, demonstrations, and other educational and outreach to inform organic and non-organic farmers of the best cover crop species and management practices for drought resilience, nutrient recovery, and improved soil water relations.
- Technical assistance to help producers select the best cover crops and practices for their locale and production system.
- Adaptation and promotion of CPS 340 for Central Valley and maritime Mediterranean climate applications, including payment schedules that ensure sufficient cost share to enable widespread implementation.

Slide 52 – *Irrigation challenges in organic production* – subtitle slide

Slide 53 – *Irrigation methods, water conservation, and soil fertility*

Overhead sprinkler irrigation results in some of the water being lost to evaporation and does not water the crop as efficiently as in-row drip irrigation. Water drop impacts can also lead to surface crusting and reduced infiltration efficiency; a problem that is largely avoided in drip irrigation.

In row drip irrigation leaves between row areas dry, which limits weed seed germination, though it can also reduce nutrient mineralization by wetting only part of the field, leaving soil life dormant in dry areas. This reduces the volume of soil from which crop roots can obtain N, other nutrients, and water, and can thereby slow crop growth, limit yield, and increased need for fertilizer applications.

Slide 54 – *Irrigation challenges in arid regions*

Some of the most productive agricultural acreages are irrigated fields in arid or semiarid regions. Irrigation mostly depends on groundwater unless snowmelt from nearby mountain ranges feeds surface waters (e.g., in the Salinas Valley of California and much of the maritime Pacific Northwest). When groundwater is drawn for irrigation of large acreages, aquifers can become depleted.

Groundwater is often saline and/or alkaline in these regions; thus, irrigation must be managed carefully to avoid soil salinization. Elevated salt levels in the topsoil can reduce yields, degrade tilth (high sodium levels disperse clays and can promote sealing and compaction), and hurt soil life. Additional irrigation may be needed to create a net downward flow of water to move salts out of the root zone. This increased water demand can increase the risk of aquifer depletion.

In addition, the native soils are low in organic matter and biological activity, because limited moisture restricts plant growth, and hence root exudate and biomass return to the soil. Thus, it is more difficult to build and maintain SOM, soil health, and resilience in these production systems.

Slide 55 – *Soil health practices in irrigated organic orchard in Utah*

Maintaining bare orchard floor with tillage or herbicides can cut SOM by half, severely damage soil health, and reduce soil AWHC (Lorenz and Lal, 2016). Irrigated orchard in Utah showed unchanged irrigation demands and significantly improved soil health and tree root development with legume (trefoil) alleys and either living mulch (shallow rooted species like alyssum) or straw mulch in tree rows (Reeve, 2014; Rowley et al., 2012). Researchers also confirmed that "mow and blow" management of the trefoil alleys contributed to tree nutrition (nitrogen uptake).

Slide 56 – *Drought puts squeeze on California tomato growers*

This project was conducted during 2016-18 by UC Davis Associate Professor of Agroecology Amelie Gaudin and organic farmer Scott Park of Park Farming Organics. Trials were conducted at UC Davis and on Scott Park's farm. While the phenomenal snowpack of 2023 is bringing substantial drought relief along with flooding problems, it is highly likely that water conservation in agriculture will continue to be vitally important in years and decades to come.

Slide 57 – *Healthy soil improves irrigation efficiency*

One objective of the UC Davis irrigation study was to determine whether Scott Park's integrated soil health building practices - diverse rotation, cover crops, compost, conservation tillage, and controlled traffic – would enhance irrigation water use efficiency in organic tomato. In the experimental treatment, irrigation was cut off at 45 days prior to harvest (compared to 30 days in the control), saving about 6 acre-inches of precious irrigation water (19% reduction) and reducing the potential for nitrate leaching. Moisture reserves in the healthy, organically managed soil were sufficient to sustain 65 ton/ac tomato yields in the deficit irrigation treatment, which was the same as in the full irrigation treatment (Gaudin, undated).

Slide 58 – *Irrigation water productivity*

In the second year of the trial, the savings in the Park Farming Organics field was only 0.17 ac-ft; however both standard and deficit irrigation treatments required much less irrigation water (0.57 – 0.74 ac-ft) than the conventional field only one mile away (1.51 – 1.71 ac-ft). Thus, the organic field had much higher irrigation efficiency (tons yield per acre-ft), especially when irrigation was cut off two weeks early with essentially no impact on yield.

An upward trend in fruit quality was also noted from the organic field, with a slightly higher phenol content and fewer rotten fruit in the organic fields.

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* OREI and ORG project reports are available through the Gateway Database at https://nifa.usda.gov/data/data-gateway. SARE project reports are available through the SARE database at https://projects.sare.org/search-projects/.