

Water Management, Water Quality, and Soil Health

Research-based Practical Guidance for Organic and Transitioning Farmers

eOrganic Soil Health and Organic Farming Webinar Series

January 9, 2019

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Presentation notes, additional information, and references to research literature on which webinar slides are based.

Slide 1 – *title slide.*

Slide 2 – *2016 National Organic Research Agenda*

A total of 1,403 respondents representing all four USDA regions (Northeast, North Central, South, and West) participated in OFRF's 2015 survey to identify top research priorities. In addition, 21 listening sessions were held in conjunction with conferences across the US.

Respondents cited water deficit / excess extremes related to climate change more often than heat or cold, although impacts of shifting temperature patterns on chilling requirements for bud break and on risks from spring frosts also emerged as serious concerns for fruit growers.

Slide 3 – *Water quantity and organic production*

Slide 4 – *Water quality and organic production*

Slide 5 – *Water quality concerns in humid and arid regions*

When groundwater is drawn for irrigation, aquifers can become depleted. In addition, groundwater is often somewhat saline, especially in drier regions, where irrigation must be managed carefully to avoid soil salinization. At Vilicus Farms Doug and Anna Crabtree implement integrated sustainable organic practices and diversified rotations that include conservation buffers (shown in the photo) and over 20 regionally adapted crops produced without irrigation, and have greatly enhanced soil health and fertility, and avoided salinity problems.

Soils in Mediterranean climates, such as California and parts of Oregon and Washington, can be prone to leaching during winter rainy seasons, yet have substantial moisture deficits and require irrigation for production during rainless summers.

Slide 6 – *Subtitle slide: effects of inherent soil properties on plant-available moisture*

Slide 7 – *What happens in soil when it rains*

Slide 8 – *Soil pore space and plant-available water*

Information on the behavior of water in soils; relative amounts of air filled, plant available and unavailable water filled pore spaces; and the impacts of soil texture, and soil health status on plant available moisture is based on Brady, N. C., and R. R. Weil, 2008. *The Nature and*

Properties of Soils. Chapters 4 (Soil Architecture and Physical Properties) and 5 (Soil Water Characteristics and Behavior).

Slide 9 – *Inherent soil properties and plant-available water holding capacity (WHC)*

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 look at your soil profile close up. The NRCS web soil survey provides valuable information on soil texture, drainage, profile, and other inherent properties for each “map unit” on your 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 10 – *How soil properties affect plant-available water in the soil profile*

In addition to the plant-available water holding capacity (WHC) 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 FC comprises 20% of the soil volume, and the crop can explore the top five feet of the soil profile, the soil can hold 12 inches of crop-available moisture. However, if the water filled pore space 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 11 – *Soil profile and plant-available water*

Some (not all) southeastern US soils have a nutrient-poor, compaction-prone E horizon between the biologically active topsoil (A horizon) and the clay-enriched subsoil (Bt horizon).

Note that, while warm season production crops often cannot penetrate the compacted E horizon in these soils, robust winter cover crops can do so, partly because of their greater ability to penetrate hardpan (e.g. radish), and partly because autumn rains moisten the soil profile, thereby decreasing the soil strength (resistance to root growth) of the E horizon.

Slide 12 – *Subtitle slide – Dynamic soil properties, WHC, and water quality*

Dynamic soil properties are those that can be modified through management: active and total soil organic matter (SOM), biological activity, soil structure (aggregation, tilth), and bulk density (degree of compaction).

Slide 13 – *Plant-available water in healthy 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 (WHC). 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. Abundant organic matter

and biological activity play major roles in maintaining good structure and WHC, as well as conferring a dark, rich color to the topsoil or A horizon. 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.

Slide 14 – How healthy soils keep crops watered

The pore network of a healthy soil includes both capillary pores within and between soil aggregates that hold plant-available moisture within the root zone, and larger pores and channels that open to the soil surface and allow rainfall and irrigation water to enter the soil promptly (moisture infiltration), and permit excess moisture to drain, thereby maintaining adequate aeration.

Slide 15 – Plant-available water in compacted soil

Poor soil management practices, including excessive tillage, overgrazing, extended bare fallow, inadequate living plant cover, 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, resulting from raindrop impact on exposed, weakly aggregated soil) closes surface pores, thereby slowing water infiltration, increasing runoff, and reducing the percentage of rain or irrigation water moves into the soil to begin with.

Compaction anywhere in the soil profile reduces total pore space, thus less water is retained at field capacity.

Larger pores are crushed into micropores, which increases the amount of hygroscopic (unavailable) water relative to capillary (plant-available) water

Air pore space is also reduced, so that roots may be oxygen-limited and unable to function normally at field capacity. Stated simply, the root zone does not drain adequately after irrigation or heavy rainfall.

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 16 – Plant-available water in depleted soil

Soils that are not compacted but have become depleted of organic matter through inadequate plant cover and organic inputs will also have reduced plant available moisture. While rainfall and irrigation water may infiltrate readily into the macropore network, much of it moves 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 rapidly 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.

Slide 17 – Effects of excessive moisture on soil health

In organic annual crop rotations, short periods of soil exposure often occur during and just after planting, during which raindrop impact can break up soil aggregates, bringing dispersed silt and clay particles into suspension. This leads to clogging of surface pores, sealing, and crust formation as the surface dries. The crust impedes infiltration of future showers and can also reduce soil aeration.

Severe prolonged drought or flooding / waterlogging can upset soil biology and degrade soil health. However, good soil health prior to the extreme event, and sound organic management practices before and after, can lessen the impacts of the adverse weather event, and allow soil life to recover after the drought breaks or the flood waters recede.

Slide 18 – *Effects of prolonged drought on soil health*

In drought prone regions, keeping the surface covered with living plants or residues can reduce wind erosion risks and maintain the ability of the soil to absorb moisture and resume plant growth and microbial activity when rains return. However, dry residues do increase fire risks. Fire is a double edged sword in prairie ecosystems. There is evidence that naturally occurring prairie fires or carefully managed prescribed burning may build stable organic matter by creating in situ biochar. However, more intense fires destroy organic matter, and of course all fires are a threat to life, livestock, and property.

When excessively wet conditions that reduce plant root health and growth are followed by a shift to prolonged dry weather, the crop's limited root system will increase its vulnerability to drought stress. In addition, the shift from ponding to dryness can accentuate compaction.

Wilson, G.W.T., C.W. Rice, M.C. Rillig, A. Springer, and D.C. Hartnett. 2009. *Soil aggregation and carbon sequestration are tightly correlated with the abundance of arbuscular mycorrhizal fungi: results from long-term field experiments*. *Ecol. Lett.* 12(5): 452–61.

Wilson, K. 2014. *How Biochar Works in Soil*. *Biochar Journal*, 2014. Excerpted by Jack Kittredge in *The Natural Farmer*. Fall 2015. *Special Supplement on Biochar in Agriculture*, pp B8-B12.. <http://thenaturalfarmer.org/issue/fall-2015/>.

Slide 19 – *Subheading slide – co-managing soil and water resources*

Slide 20 – *NRCS Soil Health Principles and water management*

Living roots and the breakdown of root residues play a vital role in creating and maintaining channels to allow moisture to infiltrate easily and excess moisture to drain out of the root zone. Crop diversification that includes species with contrasting rooting depths and root architectures can enhance water use efficiency.

Slide 21 – *Organic soil health practices and water management*

All soil health management practices that enhance active or total SOM, biological activity, and/or aggregation (structure or tilth) will improve plant-available water holding capacity, and the farming system's resilience to drought and excessive rainfalls. With the possible exception of heavy use of nutrient-rich organic inputs, nearly all soil health practices will also contribute positively to water quality.

An integrated approach to building SOM and soil health is most effective. While finished compost adds stable organic matter with its large water holding capacity, it is the continual biological activity of plant roots and soil life that maintains the desired network of interconnected large and smaller pores from surface to subsoil that is so essential to water infiltration and retention as well as adequate and prompt drainage after heavy rainfall. In addition, a diverse soil biota and diverse rotation of crops with varying root depth and architecture (taproot versus fibrous) build active and stable SOM throughout the soil profile, as well as balancing crop water demands near and below the surface and throughout the season.

Porous mulches such as straw, rolled cover crops, or landscape fabric enhance moisture infiltration by protecting the soil surface from the sealing and crusting effects of raindrop impact and direct sun, and conserve soil moisture by slowing evaporative losses. Plastic film excludes rainfall from crop rows, can aggravate runoff and erosion from alleys, and aids moisture management only if used in conjunction with in-row drip irrigation laid under the plastic.

Slide 22 – *Organic soil health practices and water management*

In addition to protecting water quality, careful nutrient management that avoids excessive levels of soluble N and P in the soil facilitates development of diverse beneficial soil biota that helps maintain an open pore network from surface to deep in the soil profile. 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. In addition, organic systems that avoid synthetic herbicides and crop protection chemicals protect soil life from potential adverse effects of these substances.

Management intensive rotational grazing, 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 WHC throughout the soil profile.

Reference on loss of SOM from high levels of soluble N:

Khan, S. A., R. L. Mulvaney, T. R. Ellsworth, and C. W. Boast. 2007. *The myth of nitrogen fertilization for soil carbon sequestration*. J. Environ. Qual. 36:1821–1832.

Fauci, M. F., and R. P. Dick. 1994. Soil Microbial Dynamics: Short- and Long-Term Effects of Inorganic and Organic Nitrogen Soil Sci. Soc. Am. J. 58 (3): 801-806.

For more resources on rotational grazing, see:

Grazing. Special supplement to The Natural Farmer, Winter 2014-15, 32 pp. In-depth how-to information on management-intensive rotational grazing systems that sequester SOM and build soil, pasture, and herd health. Articles include Mob Grazing, Allen Savory's Holistic Management system, and several farmer articles on organic dairy cattle and lamb grazing systems. <http://thenaturalfarmer.org/issue/winter-2014/>.

Carbon Farming. Special supplement to The Natural Farmer, Winter 2016-17, 32 pp. Practical C sequestration strategies that organic farms in New England utilize, including SOM accrual in management intensive rotational grazing. <http://thenaturalfarmer.org/issue/winter-2016-17-carbon-farming/>.

Slide 23 – *Healthy soil enhances drought resilience in corn production*

In the Rodale long term farming system trials, rain infiltration into the organic systems averaged 15-20% greater than in the conventional systems, resulting in less runoff and erosion. In addition, the soil profile held considerably more plant-available moisture in the organic system, which led to the difference in crop health seen here. In drought years, organic systems outyielded conventional by about 30%.

Farming Systems Trial Brochure. Summary after 35 years. 2015, 2 pp.
<http://rodaleinstitute.org/assets/FST-Brochure-2015.pdf>.

The Farming Systems Trial, Celebrating 30 Years. 2011, 21 pp.
<http://rodaleinstitute.org/assets/FSTbookletFINAL.pdf>.

Slide 24 – *Climate change, water, and soil health*

Awareness of the impacts of increasing weather extremes, especially intensifying droughts and flooding rainfalls, is now widespread throughout farming communities. In the Northeastern region, insurance claims for crop losses most frequently related to moisture extremes, followed by untimely frost or freeze (13%), heat (11%) and hail / other (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 at the surface.

The information and perspective in this slide were gained during a November 27 webinar presented by David Wolfe and Alex Hristov of the USDA Northeast Climate Hub. The North Central region has also suffered increasingly intense droughts (e.g., 2012) and floods over the past 20 years. Similarly, California went through an historic drought during 2014-17, followed by excessive rainfall that adversely affected as has California and other parts of the Western region.

Slide 25 – *Cover crop confers flood resilience*

This demonstration of the value of cover crops took place in the co-presenter's home community in Floyd County, VA, during an historic flood in 2015. The sorghum-sudan 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 floodwater.

Slide 26 – *How cover crops enhance water availability and water quality*

Cover crops should be grown to maturity (full head / bloom) to realize maximum long term benefits to SOM, soil structure, and water holding capacity. (Caveat: cover crops also consume moisture while growing; see notes for Slide 30)

The triticale + Austrian winter field pea shown here was planted in early fall and photographed at 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.

Slide 27 – *Rye breaks hardpan for cotton in South Carolina coastal plain soils*

In these trials, higher overall soil moisture content during fall and winter allowed the rye to penetrate the E horizon, opening channels for the following cotton crop to access the moisture and nutrient reserves of the underlying, clay-enriched Bt horizon. In addition, the rye 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 preceding rye cover crop enhanced volumetric soil moisture by 6.2% (~1.1 in moisture in top 18 in) and 8.5% (~1.5 in) in Fuquay loamy sand and Faceville sandy loam soils, respectively. On an *extremely* sandy soil (Lakeland sand), low cover crop biomass (500 lb/ac vs 2200 and 5000 lb/ac in Fuquay and Faceville), resulted in reduced cover crop benefits.

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

Marshall, M.W., P. Williams, A. Mirzakhani Nafchi, J. M. Maja, J. Payero, J. Mueller, and A. Khalilian. 2016. *Influence of Tillage and Deep Rooted Cool Season Cover Crops on Soil*

Properties, Pests, and Yield Responses in Cotton. Open Journal of Soil Science , 6, 149-158.
<http://dx.doi.org/10.4236/ojss.2016.610015>

Slide 28 – *Tillage radish: master subsoiler and nutrient scavenger*

A study of corn and soybean rooting density versus depth in the profile of a compacted soil showed significantly greater deep root growth after radish than after winter rye, which in turn improved deep root development over no cover.

Gruver, J., R. R. Weil, C. White, and Y. Lawley. 2016 *Radishes A New Cover Crop for Organic Farming Systems*. <http://articles.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farming-systems>.

Chen, G., and R. R. Weil. 2010. Penetration of cover crop roots through compacted soils. *Plant and Soil* 331: 31–43. (Available online at: <http://dx.doi.org/10.1007/s11104-009-0223-7>)

Radish root photo taken at Center for Environmental Farming Systems (CEFS) in Goldsboro, NC during the July, 2016 Southern SARE Cover Crop Conference. Proceedings and other resources available at <https://www.southernsare.org/Events/Southern-Cover-Crop-Conference>.

Slide 29 – *Pearl millet and sorghum-sudangrass*

Sorghum-sudangrass and pearl millet form robust root systems that are both deep and fibrous. Mowing the crops at the pre-heading stage (3 to 5 ft height) stimulates additional root growth during regrowth.

Pearl millet has demonstrated an ability to penetrate naturally compacted and acidic subsurface soil layers that stop the root growth of most other crops, effectively scavenging nitrate-N from within and below the compaction layer, to depths of 4 to 7 feet. In addition to protecting water quality and conserving N, this trait can help following crops access deep moisture reserves.

Rosolem, C. A., K. Ritz, H. Cantarella, M. V. Galdos, M. J. Hawkesford, W. R. Whalley, and S. J. Mooney. 2017. *Enhanced plant rooting and crop system management for improved N use efficiency*. *Advances in Agronomy* 146: 205-239.

Menezes, R. S. C., G. J. Gasho, W. W. Hanna, M. L. Cabrera, and J. E. Hook. 1997. *Subsoil nitrate uptake by grain pearl millet*. *Agronomy Journal*, Vol. 89 No. 2, p. 189-194.

Slide 30 – *Soil moisture use by cover crops*

While cover crops consistently improve soil health and water holding capacity in the long run, they can reduce soil moisture in the short run while they are growing. Water consumption by a mature, high biomass cover crop can be substantial. In higher rainfall regions (east of the Mississippi), winter cover crops can serve to remove excessive soil moisture and facilitate timely planting. Since rainfall patterns vary year to year (especially with climate change), the challenge is to terminate the cover crop when soil moisture is just right for planting – and the timing can differ in successive seasons.

In semiarid regions, the traditional two year cereal grain / fallow rotation is used to save up two years' worth of moisture, but multiple studies have shown that the prolonged fallow degrades SOM and water holding capacity, even in no-till systems. Diversifying the rotation by adding pulse, oilseed, and/or cover crops during the fallow year improves soil health and WHC, yet can reduce grain yields by consuming moisture in the short run. Some producers have had great success with cover crops, while others have observed severe yield tradeoffs related to

moisture. Care is needed in selecting the cover crop, planting and termination dates in order to minimize impacts on moisture available to the following crop.

Winter-planted field peas have offered significant benefits (N, weed suppression, long term soil health) and are relatively light consumers of soil moisture.

Effects of cover crops on yields of a subsequent wheat crop in four years of trials on 20 farms in eastern Washington (9 – 13 inches annual moisture) varied depending on topsoil moisture remaining after the cover crop was terminated. When cover crops left sufficient moisture for wheat germination, grain yields were unaffected or increased; when the cover crop depleted moisture in the top 3 – 6 inches, wheat stands and yields suffered.

Menalled F., C. Jones, D. Buschena, and P. Miller. 2012. *From Conventional to Organic Cropping: What to Expect During the Transition Years*. Montana State University Extension MontGuide MT200901AG Reviewed 3/12. <https://store.msuxextension.org/>.

Michel, L. 2018. *Meeting the Challenges of Soil Health in Dryland Wheat*. NRCS webinar October 9, 2018. Science and Technology Training Library, <http://www.conservationwebinars.net/listArchivedWebinars>.

Miller, P. R.; D. E. Buschena, C. A. Jones, B. D. Maxwell, R. E. Engel, F. Menalled, and B. J. Jacobsen. 2009. *Organic Production in the Challenging Environment of the Northern Great Plains: from Transition to Sustainability*. Final report for ORG project 2005-04477. CRIS Abstracts.

White, C., Barbercheck, M., DuPont, T., Finney, D., Hamilton, A., Hartman, D., Hautau, M., Hinds, J., Hunter, M., Kaye, J., La Chance, J. 2016. *Making the Most of Mixtures: Considerations for Winter Cover Crops in Temperate Climates*. eOrganic, <http://articles.extension.org/pages/72973/making-the-most-of-mixtures;-considerations-for-winter-cover-crops-in-temperate-climates>.

Slide 31 – *Choosing cover crops for semiarid regions*

While all of these crops are adapted to thrive in drier regions, crops like alfalfa, sunflower, and radish tolerate drought through deep, extensive root systems that efficiently extract moisture throughout the soil profile and thus can aggravate moisture deficits for the following crop. In contrast, field pea, medic, and pearl millet require much less moisture to complete their life cycles, and can provide cover crop benefits with less consumption of precious soil moisture.

USDA, Agriculture Research Service (ARS), 2018. Cover Crop Chart, V 3.0. Northern Great Plains Research Laboratory at Mandan, ND. 74 pp. 1. <https://www.ars.usda.gov/plains-area/mandan-nd/ngprl/docs/cover-crop-chart/>.

Slide 32 – *Diversified crop rotations in organic dryland production*

Vilicus Farms spans 7,400 acres, about one-quarter of which is in permanent conservation plantings, and the remainder in five to seven year crop rotations carefully designed to maximize water use efficiency and soil health while sustaining profitable yields. <https://www.vilicusfarms.com/>.

Slide 33 – *Compost, manure, and other organic amendments*

Smaller scale producers and gardeners commonly use large amounts of compost to build soil water holding capacity and overall soil health and fertility. While compost adds stable SOM and thereby WHC, overuse thereof can build excess soil P, which inhibits mycorrhizal fungi and can potentially cause P to enter surface waters via runoff. The root-mycorrhizal fungal symbiosis

plays a vital role in moisture uptake efficacy and drought resilience in grain, legume, and some vegetable crops, notably tomato and onion families. Building up very high SOM levels through heavy compost and manure applications can result in sufficient N mineralization by soil life to leach excess N to groundwater.

Judicious use of concentrated organic nutrient sources such as manure and pelleted poultry litter fertilizers (NPK), and feather and blood meals (N) can benefit water management by optimizing cover and cash crop growth (organic input to the soil, building long term WHC) and maintaining cash crop yield (and thus financial return on water used). However, heavy use of these materials can compromise soil biology and water quality as noted above.

Some heavy feeding crops such as broccoli present a challenge, in that optimum N rates (feather, blood, and/or meat meals) in terms of yield and net return can result in significant N leaching. Additional N leaching from broccoli residues incorporated ahead of a slow-starting crop like strawberry has been documented in California.

Concentrated organic nutrient sources such as poultry litter can also result in lower SOM levels in the long run, compared to the use of more diverse organic inputs with higher mean carbon:nitrogen ratio.

Cavigelli, M. A., S. Mirsky, and J. E. Maul. 2014. *On-farm Research and Extension to Support Sustainable Nutrient Management of Organic Grain Cropping Systems in the Mid-Atlantic Region*. Final report for OREI project 2009-01361. CRIS Abstracts.*

Collins, D. P. and A. Bary. 2017. *Optimizing nitrogen management on organic and biologically intensive farms*. Proceedings of the Special Symposium on Organic Agriculture Soil Health Research at the Tri-Societies Annual Meeting, Tampa, FL, October 22-25, 2017. <http://articles.extension.org/pages/74555/live-broadcast:-organic-soil-health-research-special-session-at-the-tri-societies-conference>.

Li, C., Salas, W. and Muramoto, J. 2009. *Process Based Models for Optimizing N Management in California Cropping Systems: Application of DNDC Model for nutrient management for organic broccoli production*. Conference proceedings 2009 California Soil and Plant Conference, 92-98. Feb. 2009. <http://ucanr.edu/sites/calasa/files/319.pdf>.

Muramoto, J., C. Shennan, and J., M. Gaskell. 2015. *Nitrogen management in organic strawberries: challenges and approaches*. (Webinar) <http://articles.extension.org/pages/73279/nitrogen-management-in-organic-strawberries:-challenges-and-approaches>

Bhowmik, A. A-M. Fortuna, L. J. Cihacek, A. Bary, P. M. Carr, and C. G. Cogger. 2017. *Potential carbon sequestration and nitrogen cycling in long-term organic management systems*. Renewable Agriculture and Food Systems, 32 (6): 498-510.

Slide 34 – *Weeds steal soil moisture*

Slide 35 – *Cultivation and soil*

Shallow cultivation leaves most of the soil profile undisturbed, and if done when weeds are small, can be highly effective. However, repeated cultivation passes (often needed to ensure weed control) can pulverize the soil surface, and can lead to 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 alternatives such as mowing, mulching, grazing, and/or thermal (flame, steam, hot water) weeding are implemented.

Slide 36 – *Mulching saves 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.

Synthetic (plastic) mulches block weed growth and competition more completely, but do not add organic matter. Plastic film mulches 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 can also erode soil from alleys in sloping fields.

Weed mat (= landscape fabric) is porous, allowing rain or overhead irrigation water to enter the soil profile in crop rows, while maintaining excellent weed control. Unlike film, it can also be reused for up to 10 seasons or more.

Schonbeck, M. S., and G. K. Evanylo. 1998. *Effects of Mulches on Soil Properties and Tomato Production*. I. Soil temperature, soil moisture, and marketable yield. *J. Sustainable Agric.* 13(1): 55-81.

Slide 37 – *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. 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. 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.

Cogger, C. G. M. Ostrom, K. Painter, A. Kennedy, A. Fortuna, R. Alldredge, A.; Bary, T. Miller, D. Collins, J. Goldberger, A. Antonelli, and B. Cha. 2013. *Designing Production Strategies for Stewardship and Profits On Fresh Market Organic Farms*. Final report for OREI project 2008-01247. CRIS Abstracts.*

Wortman, S., C. Francis, R. Drijber, and J. Lindquist. 2016. *Cover Crop Mixtures: Effects of Diversity and Termination Method on Weeds, Soil, and Crop Yield*. Midwest Cover Crop Council, http://mccc.msu.edu/wp-content/uploads/2016/12/NE_2016_Cover-Crop-Mixtures_-_Effects-of-Diversity-and-Termination.pdf.

Schonbeck, M., D. Jerkins, and J. Ory. 2017. *Soil Health and Organic Farming: Practical Conservation tillage*. <https://ofrf.org/>.

Slide 38 – *Subtitle slide – co-managing soil and water in irrigated systems and high tunnels*

Slide 39 – *Irrigation management and soil health*

PNW Extension nutrient management accounts for nitrate N in irrigation water.

Oregon State U. Extension bulletin EM 9165, *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon*, by D.M. Sullivan, E. Peachey, A.L. Heinrich, and L.J. Brewer, May, 2017.

Slide 40 – *Irrigation management and soil health*

In row drip irrigation leaves between row areas dry, which limits weed seed germination and thereby reduces future competition for water. It can also reduce nutrient mineralization by wetting only part of the field, leaving soil life dormant in dry areas (may protect groundwater, and may also reduce nutrient availability to crops).

Slide 41 – *Healthy soil improves irrigation efficiency in UC Davis on-farm trial*

In an OFRF-funded on-farm study, Dr. Amelie Gaudin at University of California at Davis and farmer collaborator Scott Park of Park Farm Organics, conducted experiments to determine whether the farmer'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. Increasingly severe droughts, high cost of irrigation water, and concerns about N leaching (lost nutrients, groundwater pollution) have made water use efficiency a top priority for California farmers.

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 water (19% reduction) and reducing the potential for nitrogen leaching. Moisture reserves in the healthy, organically managed soil were sufficient to sustain 65 ton/ac tomato yields in the deficit irrigation treatment (same as controls).

For more information, search database at <https://ofrf.org/research/database>, under Amelie Gaudin, or see video at https://www.youtube.com/watch?v=yapM4_SUu6I.

Slide 42 – *Irrigation management in organic berry crops*

Studies at Oregon State University showed that in-row drip irrigation under a moisture-conserving mulch is best for maintaining just the right soil moisture level for organic blueberries, which have fairly shallow root systems and are sensitive to drought and to excessive moisture (“wet feet”). Compared to weed mat (shown), organic mulch (sawdust) promoted greater root growth and reduced irrigation needs.

In blackberry, researchers and farmer cooperators found that post harvest irrigation could be omitted without affecting yield potential, thereby saving about 2.5 acre-inches of water per year. In addition, omitting late season irrigation improved winter hardiness.

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Slide 43 – *Managing for healthy soil in irrigated organic orchard in Utah*

Maintaining bare orchard floor with tillage or herbicides can cut SOM by half and severely damage soil health, and may not save on irrigation water. 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. Researchers also confirmed that “mow and blow” management of the trefoil alleys contributed to tree nutrition (nitrogen uptake).

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Rowley, M., B. Black, and G. Cardon. 2012. *Alternative Orchard Floor Management Strategies*. Utah State University Cooperative Extension, Horticulture/Fruit/2012-01pr, 4 pp.

Slide 44 – *Water, salt, and nutrient management in the high tunnel*

The high tunnel environment resembles a semiarid ecosystem, since natural rainfall is excluded, and irrigation water is normally provided via in-row drip at rates that may not keep up with total evaporation + transpiration. This results in a net upward movement of moisture and dissolved salts and nutrients, a situation with which growers in high rainfall regions may not be familiar.

Intensive production and fertility inputs can lead to a buildup of salts, especially if irrigation water is saline or alkaline. Well water (groundwater) can be rich in sodium and/or calcium even in higher rainfall regions, depending on local mineralogy and hydrology. Thus, soil salinity should also be monitored, and leached out as needed before crop-limiting levels are reached. This can be done either by removing the plastic roof for several months where natural rainfall is sufficient to leach out salts, or by means of a heavy sprinkler irrigation.

Nutrient surpluses, especially phosphorus (P) and sometimes nitrate-N or other nutrients, can also occur. Compost and other fertilizer inputs should be calibrated to keep annual P inputs in balance with P removal in harvests, and to minimize salt loading. Legume-containing cover crop mixes can add organic matter and N without P, other nutrients, and salts.

Slide 45 – *Acknowledgement of OFRF funders*

Slide 46 – *Questions*