**Preparing for Drought: The Role of Soil Health in Water Management in Organic Production**

*Research-based Practical Guidance for Organic and Transitioning Farmers in the Western Region*

eOrganic Soil Health and Organic Farming Webinar Series

April 17, 2019

Developed and presented by Organic Farming Research Foundation, with funding from the Western Region SARE program

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

NOTE: Slides 38 - 41 are borrowed with permission from Zahangir Kabir, NRCS, Davis, CA. Slide 43 is used with permission from Joji Muramoto at UC Santa Cruz. Slides YYY are based on a presentation by Lauren Snyder summarizing the work of Scott Park and Dr. Amelie Gaugin in Davis, CA.

Slide 1 – *title slide*.

Slide 2 – *2016 National Organic Research Agenda – water-related research priorities*

 A total of 555 respondents from the Western region participated in OFRF’s 2015 nationwide survey of organic farmers to identify top research priorities. In addition, six listening sessions took place in the West (four in CA, two in OR).

 Additional topics cited by farmers include drought management in pasture, and improving moisture capacity with compost.

Slide 3 – *Water quality and organic production*

Slide 4 – *Water quality concerns in different regions and production systems*

 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. In the Salinas Valley, vegetable fields are double-cropped between April and November, receiving as much as 35 inches of irrigation water, then left fallow during the winter rainy season when most of the region’s 16 inches of annual rainfall occurs, sometimes leaching more than 200 lb nitrate-N per acre (Wyland et al., 1996).

 Dryland crop production in low-rainfall regions can face a different problem: the net upward movement of moisture in the soil profile can concentrate soluble salts in the topsoil. Careful management of soil health, soil moisture, and crop rotations can minimize salinity problems. At Vilicus Farms in Hill County, Montana, Doug and Anna Crabtree have implement integrated sustainable organic practices and diversified rotations that include conservation buffers (shown in the photo) and over 20 regionally adapted cash and cover crops. They have greatly enhanced soil health and fertility, and avoided salinity problems.

 Wyland, L. J., L. E. Jackson, W. E. Chaney, K. Klonksi, S. T. Koike, and B. Kimple. 1996. *Winter cover crops in a vegetable cropping system: impacts on nitrate leaching, soil water, crop yield, pests and management costs.* Agriculture, Ecosystems and Environment 59: 1-17.

 Website for Vilicus Farms is <https://www.vilicusfarms.com/>.

Slide 5 – *Effects of inherent soil properties on plant-available moisture*

Slide 6 – *What happens in soil during rainfall*

 Water that moves downward through the largest pores after a rain event or irrigation is called “gravitational water” – it can be stored deeper in the soil profile or return to the water table.

 At field capacity (after gravitational water drains out), the soil holds plant available “capillary” water in medium to small pores, and “hygroscopic” water held too tightly in the smallest pores for plants to take up.

 During dry spells, when plants have utilized all the plant-available capillary water, leaving only the hygroscopic water, the soil moisture has reached the “wilting point”. If the entire soil profile to rooting depth has reached this point, the plant wilts or rolls its leaves and stops growing until rain or irrigation replenish soil moisture.

Slide 7 – *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 8 – *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 ([*https://websoilsurvey.nrcs.usda.gov/*](https://websoilsurvey.nrcs.usda.gov/)) provides valuable information on soil texture, drainage, profile, 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.

 The example in the photo, Woodburn silt loam (Argixerolls), is a very deep, moderately well-drained soil with moderately slow permeability. It developed in a moist Mediterranean climate (40 – 50 inches annual rainfall, mostly in winter with warm dry summer and 45 – 80 days of dry soil conditions). Saturated (aquic) conditions occur 20-30 inches below the surface for part of the year, which will limit rooting depth of crops growing at those times of year. If the water table drops and the soil profile dries *rapidly* with the onset of the dry season, this could leave the earlier-planted, shallow-rooted crops prone to drought stress.

Slide 9 – *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 10 – *Soil profile and plant-available water*

 The Chualar soil is described as very deep (>5 ft to unwewathered parent material) and well drained, yet bulk density begins to increase below 6 inch depth and becomes high enough (>1.6) to stop root growth at 30 inches. As a result, moisture and dissolved nitrate-N and other nutrients can leach below this depth, yet crop roots cannot access them.

 Wyland et al., 1996, cited above.

Slide 11 – *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 12 – *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 13 – *How healthy soils keep crops watered*

 Soil organic matter (SOM) enhances plant-available water holding capacity (WHC) in several ways. SOM itself has a high volumetric water holding capacity, and, in silt-loams, WHC as % of total soil volume increases about 4% for each % SOM (i.e., WHC pore space is ~12% of soil volume at 1% SOM, increasing to about 32% WHC at 6% SOM) (Hudson, 1994).

 SOM and soil life also enhance WHC by improving soil structure. 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.

 Hudson, B. D. 1994. Soil organic matter and available water capacity. J. Soil and Water Conservation 49: 189-194, cited in Weil and Brady, 2017.

Slide 14 – *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.

 A subsurface hardpan (which can result from repeated plowing or other tillage to the same depth, and lack of deep rooted crops in the rotation) can stop root growth and prevent the crop from accessing deep moisture reserves.

 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. In addition, air pore space is reduced, so that when soil moisture level is at or near field capacity, inadequate aeration limits root function and moisture uptake. As the soil dries below field capacity, increasing soil strength (resistance to root penetration) slows root growth and moisture uptake well before moisture levels reach the wilting percentage. Thus, compaction severely restricts both root volume and the effective WHC percentage of the soil.

 Weil and Brady, 2017, cited above.

Slide 15 – *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 can result from a combination of inherent (texture) and dynamic (management related) properties.

Slide 16 – *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.

 Prolonged flooding / waterlogging can upset soil biology and degrade soil health, as can severe drought. 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 17 – *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 18 – *Co-managing soil and water resources in organic production*

Slide 19 – *NRCS soil health principles and water management*

 Living roots and the breakdown of root residues build SOM, maintain aggregation (tilth), and create channels to allow moisture to infiltrate easily and excess moisture to drain out of the root zone. Diversified crop rotations that include species with contrasting rooting depths and root architectures maximize these structural benefits, and can enhance water use efficiency by balancing crop water demands from shallow and deep soil horizons, and throughout the season. Cover crops play a central role in effective water management in annual cropping systems and orchard / vineyard floor. Cover cropping strategies for regions with different rainfall pattern will be discussed in depth later in this presentation.

Slide 20 – *Organic soil health practices and water management*

 The National Organic Standards require soil health management practices that build and maintain SOM, biological activity, and aggregation. These practices also protect water quality, build plant-available water holding capacity, and enhance the farming system’s resilience to drought and excessive rainfalls.

Slide 21 – *Nutrient management and compost*

 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 play central roles in maintaining an open and interconnected 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. Organic production systems that use slower-release organic and natural mineral nutrient sources generally maintain lower soluble nutrient levels and thus more hospitable conditions for beneficial soil organisms.

 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.

 Smaller scale organic producers who must make a living on limited acreage and plant multiple production crops per year (and hence fewer or no cover crops) 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 of compost or manure can build excess soil P, which inhibits mycorrhizal fungi and can lead to P runoff to surface waters. The root-mycorrhizal fungal symbiosis helps build stable SOM and plays a vital role in moisture uptake efficacy and drought resilience in grain, legume, and some vegetable crops, notably tomato and onion families.

 In addition, building up very high levels of active SOM through heavy compost and manure applications can result in sufficient N mineralization by soil life to develop high soluble N levels and 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 soil and water management by optimizing cover and cash crop growth (organic input to the soil) and maintaining cash crop yield (and thus financial return on water used). However, relying on concentrated organic nutrient as the primary fertility source can result in lower SOM levels than the use of more diverse organic inputs with higher mean C:N ratio,.

 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

 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.\*

 Delate, K., C. Cambardella, and C. Chase. 2015a. Effects of cover crops, soil amendments, and reduced tillage on carbon sequestration and soil health in a long term vegetable system. Final report for ORG project 2010-03956. CRIS Abstracts\*

 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.

  Hooks, C. R., K. H. Wang, G. Brust, and S. Mathew. 2015. Using Winter Cover Crops to Enhance the Organic Vegetable Industry in the Mid-Atlantic Region. Final report for OREI project 2010-01954. CRIS Abstracts.\*

  Mulvaney, R. L., S. A. Khan, and T. R. Ellsworth. 2009. Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production. J. Environ. Qual. 38:2295–2314.

Slide 22 – *Mulching can save 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 and feed soil life (thus maintaining structure and WHC), and protect the surface from raindrop impact and crusting (thus improving moisture infiltration). In a mulching systems study for organic tomato, 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.

 Weed mat (= landscape fabric) is a porous synthetic mulch that allows rain or overhead irrigation water to enter the soil profile in crop rows, while maintaining excellent weed control (much better than straw). It also provides some protection from rain impact and thus reduces crusting. Unlike plastic 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 23 – *Plastic film mulch and runoff*

 Synthetic (plastic) mulches are widely used in organic vegetable and strawberry production to maintain higher soil temperatures, conserve moisture, prevent fruit rot and stop weeds. However, they also block rain and overhead irrigation, and thus require drip irrigation tape under the film in order to deliver water to crops. In addition 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 need for irrigation during the next dry season), and can carry off nutrients and soil.

In central California, both organic and conventional strawberries 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 runs off carrying soil and nutrients out of the field.

Slide 24 – *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

 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.\*

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

Slide 25 – *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 WHC throughout the soil profile.

 Multiple studies in both humid and semiarid regions show that MIG systems can restore grassland soils to near native SOM levels, which result in far better moisture holding capacity and higher quality forages with increased drought tolerance.

 Rancher Gabe Brown has restored 5,000 acres of cropland and grassland at his North Dakota ranch by implementing the NRCS four soil health principles and MIG for livestock. Over a 20 year period, SOM increased from less than 2 percent to more than 6 percent, and Brown estimates that soil WHC has increased by about four-acre-inches (100,000 gallons/ac) as a result.

 **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/>.

 Brown, G. 2018. *Dirt to Soil: one family’s journey into regenerative agriculture*. Chelsea Green Publishing, White River Junction, VT.

Slide 26 – *Weeds steal soil moisture*

 The exclusion of most synthetic agrochemicals from organic systems protects water quality and soil life; however weed management can become a challenge. Weeds steal soil moisture from crops – and from desirable forage species in pasture and range. While management-intensive rotational grazing of livestock can keep most weeds in check, some invasive exotic weeds such as knapweeds, star thistle, and Canada thistle can displace native prairie plant species and degrade range by excessively depleting moisture throughout the soil profile, and/or secreting root exudates that are hostile to the native prairie soil microbiome.

Slide 27 – *Cultivation and organic weed IPM*

 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 in some organic crops) 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 organic 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.

 Schonbeck, M., D. Jerkins, and J. Ory. 2017. *Soil Health and Organic Farming. Weed Management: an Ecological Approach.* <https://ofrf.org/>.

Slide 28 – *Co-managing soil and water resources in organic production in the Western Region: irrigated crops*

Slide 29 – *Irrigation methods and soil health*

 In row drip irrigation can reduce nutrient mineralization by wetting only part of the field, leaving soil life dormant in dry between-row areas.

Slide 30 – *Irrigation challenges in arid regions*

 Some of the most productive agricultural acreages are irrigated fields in arid or semairid 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 and water-holding capacity (high sodium levels disperse clays, promote sealing and compaction), and hurt soil life. Additional irrigation may be needed to move the salts out of the root zone, which increases drawdown of aquifers.

 In addition, many soils of dry regions (Aridisols) are low in organic matter and biological activity, because limited moisture restricts plant growth, and hence rhizodeposition 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 31 – *Managing for healthy soil in irrigated orchard in Utah*

 Maintaining bare orchard floor with tillage or herbicides can cut SOM by half, severely damage soil health, cut soil WHC, and does 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).

 Lorenz, K., and R. Lal. 2016. *Environmental Impact of Organic Agriculture. Advances in Agronomy* 139: 99-152.

 Reeve., J. 2014. *Organic Stone Fruit Production: Optimizing Water Use, Fertility, Pest Management, Fruit Quality and Economics.* Final report for OREI project 2009-01338, CRIS Abstracts.\*

 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 32 – *Drought puts squeeze on California tomato growers*

Slide 33 – *Healthy soil improves irrigation efficiency*

 In an OFRF-funded on-farm study in 2016-18, Dr. Amelie Gaudin of 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 2016 trial, irrigation was cut off at 45 days prior to harvest (deficit irrigation) or 30 days before harvest (control treatment, standard practice) Deficit irrigation saved about 6 acre-inches of precious irrigation 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 34 – *Irrigation water productivity*

 Additional trials were conducted in 2017 at Park Farm and in a nearby conventionally managed field. In this second year of trials, the savings in the Park organic field was only 0.17 ac-ft; however both standard and deficit irrigation 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 trend toward higher phenol content and less rotten fruit on the organic fields.

Slide 35 – *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.

 Strik, B., D. Bryla, and D. Sullivan. 2015. *Organic Blueberry Production Research Project.* <http://articles.extension.org/pages/31680/organic-blueberry-production-research-project>.

 Strik, B., D. Bryla, D. Sullivan, and C. Seavert. 2011. *Integrated Weed Management and Fertility in Organic Highbush Blueberry Production Systems to Optimize Plant Growth, Yield, and Grower Return.* Final report for OREI project 2008-01237. CRIS Abstracts.\*

 Strik, B., D. Bryla, and L. Valenzuela. 2014. *Organic Blackberry Production: Tips Learned from an Ongoing Research Study*. [http://articles.extension.org/pages/70279/organic-blackberry-production:-tips-learned-from-an-ongoing-research-study](http://articles.extension.org/pages/70279/organic-blackberry-production%3A-tips-learned-from-an-ongoing-research-study).

Slide 36 – *Co-managing soil and water resources in organic production in the Western Region: some research findings in irrigated crops in maritime Mediterranean climates.*

Slide 37 – *The problem of winter fallow in Mediterranean climates*

 With mild summer temperatures near the coast and available water from mountain snow melt, 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, and usually requires irrigation. This seasonal pattern leaves fields fallow and subject to soil degradation during the rainy season.

Slide 38 – *Comparing winter cover crops versus fallow at grower-collaborator field site*

 The following four slides were generously shared by Dr. Zahangir Kabir, NRCS Soil Health Specialist at Davis, CA. His presentation notes for this slide:

 “We use an ISCO water sampler that was able to measure runoff minute by minute.”

Slide 39 – *Winter runoff, Russell Ranch, UC Davis*

 Dr. Kabir states: “After a rainfall event, in Fallow plot, rain water was remaining on the surface and draining into the water body whereas in cover crop plot rain water was remaining in the field (i.e. saving account) by improving infiltration, therefore, in summer use less irrigation water.”

 Note how much difference that even a young cover crop that has not yet developed a lot of aboveground biomass has made to the soil’s capacity to absorb rainfall. Based on a data slide not shown here, the fallow field lost nearly half of the 8 inches of rain that fell between mid January and mid March, while the cover cropped treatments retained 90% of that rainfall.

Slide 40 – *After a storm event in Solano walnut orchard*

 Dr. Kabir’s notes: “I took these photograph in the same day close to each other in same soil type. Only difference is the cover crops. Poor soil structure which is associated with poor soil health causes the water not to infiltrate.”

 Saturated soil conditions will deter beneficial aerobic soil micro-organisms and result in emissions of greenhouse gases including methane and/or nitrous oxide.

Slide 41 – *Another side-by-side cover crop / fallow comparison after a heavy rainfall*

 Dr. Kabir’s notes: “I took these photos, other side of the County Road 98 near woodland, CA after a heavy rain fall event (about 2” of RF) wit the same soil. As you can see, two fields opposite side of the road. The important differences is cover crop vs fallow. Cover crop field all rain water infiltrated but the fallow field soil is sealed off due to rain fall impact and remaining on the field and running off from the field.” (Z. Kabir)

Slide 42 – *Organic vegetables with winter fallow*

 From central California to the maritime Pacific Northwest, summer crop production followed by winter fallow commonly results in substantial leaching of nitrate-N with the downward movement of water. This occurs even in organic production of heavy feeders like broccoli. Studies in Oregon and California showed strong broccoli yield response to organic N (from feather, blood and/or meat meals) at rates up to 220 lb/ac, with 11 to 88 lb broccoli per lb N, for a net economic return of $4 – 34 per $1 on fertilizer (at market price of $2.50/lb for broccoli, and $6.36/lb N from feather meal). Because broccoli harvest removed only a fraction of the N, substantial leaching losses followed, estimated in the CA study at up to 180 lb/ac.

 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](http://articles.extension.org/pages/74555/live-broadcast%3A-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>.

Slide 43 - *Asynchrony of N supply and N demand in an organic strawberry field in the Northern region, CA*

 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 and strawberry planting. The goal was to utilize leftover broccoli N to meet strawberry 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.

This slide is taken from a 2015 webinar with permission from Dr. Joji Muramoto of University of California at Santa Cruz.

 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](http://articles.extension.org/pages/73279/nitrogen-management-in-organ%1Fic-strawberries%3A-challenges-and-approaches).

 Gaskell, M., M. Bolda, J. Muramoto, and O. Daugovish, 2009. *Strawberry Nitrogen Fertilization from Organic Nutrient Sources.* Acta *Horticulturae* (ISHS) 842:385-388.

Slide 44 – *Organic vegetables + cover crop*

 While strawberry planted after broccoli cannot utilize the leftover N, vigorous, deeper-rooted winter cover crops can do so quite effectively.

 Winter rains leached some 230 lb nitate-N/ac from a bare fallow soil profile after heavily fertilized conventionally grown vegetables on a Chualar loamy sand (well drained but high bulk density restricts root growth at and below 30-inch depth) in the Salinas Valley of California. 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).

 In an eight-year trial (Salinas Organic Cropping Systems Experiment) conducted on the same soil type in the Salinas Valley by Dr. Eric Brennan of USDA Agricultural Research Service, a double cropping system of spring lettuce followed by fall broccoli sustained high lettuce yields (1000 boxes/ac, about 30 lb/box) only when a winter cover crop was grown prior to the lettuce. In the system that left the field fallow three winters out of four, lettuce yields declined sharply to a few hundred boxes per acre, and sometimes to a total crop failure. Cover crops of rye alone, mustard, or rye with vetch, fava, and pea were similarly effective, indicating that their main benefit was not N fixation *per se*, but recovery of N left over from the broccoli crop. Broccoli was fertilized with about 145 lb N/ac (from NOP allowed organic sources), only about 25% of which was removed in harvest. During winter fallow, leaching by heavy winter rains falling on the sandy soil depleted soil N, whereas vigorous winter cover crops recovered N and their residues delivered it to the lettuce.

 In addition, cover crops enhanced microbial activity while compost contributed stable SOC, and thus worked together to improve WHC.

 Brennan, E. 2018. Lessons from long-term, cover crop research in the Salad Bowl of the World – 10 minute youtube video, <https://www.youtube.com/watch?v=JurC4pJ7Lb4>

 Brennan, E. B., and V. Acosta-Martinez. 2017. Cover cropping frequency is the main driver of soil microbial changes during six years of organic vegetable production. Soil Biology and Biochemistry 109: 188-204.

 Wyland, L. J., L. E. Jackson, W. E. Chaney, K. Klonksi, S. T. Koike, and B. Kimple. 1996. *Winter cover crops in a vegetable cropping system: impacts on nitrate leaching, soil water, crop yield, pests and management costs.* Agriculture, Ecosystems and Environment 59: 1-17.

Slide 45 – *The challenge of getting the cover crop planted*

 If cover crops can save so much moisture and N, why don’t all West Coast vegetable growers plant them? Practical challenges often arise in planting cover crops after harvest.

 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. Winter cover crop growth can also be constrained by excessive moisture, or by freezing temperatures in northern or inland locations.

Slide 46 – *Interseeding cover crops*

 Interseeding cover crops into standing cash crops can facilitate establishment and maximize soil coverage. Several examples are shown here including (clockwise from top left) legume cover crops planted between rows of kale (shown here at mid-growth) in western Washington, red clover in butternut squash (harvest-ready) and oats in eggplant (post harvest – frost-killed stalks remaining) in western Oregon, and 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.

 In a 2006 field trial, cereal grain (barley or triticale) was planted in furrows between plastic mulched strawberry beds in November. The cover crops were mowed in January to prevent competition with strawberry. The trial was conducted on a poorly drained soil and the cover crop did not reduce the quantity of runoff or soluble N or P losses; however sediment (mineral and organic materials) and *total* N and P loses were reduced 70, 47, and 40% respectively by the cover crop.

 Because cereal grains regrow after mowing and may be difficult to manage in organic systems, Brennan et al tested ‘Ida Gold’ mustard as a furrow cover planted in November or December, several weeks after strawberry transplanting. This crop scavenged about 22 lb nitrate-N per acre, and was easily killed with a weed whacker in February (just before it grew tall enough to begin shading the strawberry crop).

 Cahn, M., M. Bolda, and R. Smith. 2006a. Winter cover crops for reducing storm run-off and protecting water quality in strawberries, p. 2–4. Crop notes. Univ. California Coop. Ext., Monterey County, CA. 5 Mar. 2018. [http://cemonterey.ucanr.edu/newsletters/November-December,\_200632272.pdf](http://cemonterey.ucanr.edu/newsletters/November-December%2C_200632272.pdf).

 Brennan, E. B., and R. F. Smith. 2018. Mustard Cover Crop Growth and Weed Suppression in Organic Strawberry Furrows in California. HortScience 53(4):432–440.

Eric Brennan video *Furrow cover crops for 'Greener' strawberries and other plastic mulched crops.* <https://www.youtube.com/watch?v=fesxbH03diY>.

Slide 47 – *Co-managing soil and water resources in organic production in the Western Region: some research findings from the semiarid interior.*

Slide 48 – *Dryland challenges*

 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, 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; 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 soil WHC in the long term.

 The traditional two year wheat / fallow rotation aims to save up two years’ worth of rainfall for the cash crop, but the prolonged fallow degrades SOM and soil health, 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.

 Lehnhoff, E., Z. Miller, P. Miller, S. Johnson, T. Scott, P. Hatfield, and F. D. Menalled. 2017. Organic Agriculture and the Quest for the Holy Grail in Water-Limited Ecosystems: Managing Weeds and Reducing Tillage Intensity. Agriculture 2017, 7, 33; doi:10.3390/agriculture7040033 [www.mdpi.com/journal/agriculture](http://www.mdpi.com/journal/agriculture).

 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.msuextension.org/> .

 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.\*

Slide 49 – *Cover crops for semiarid climates*

 Studies in the Northern Great Plains (Montana) and the Palouse region of southeast Washington have shown that a winter cover crop of field peas can build soil health, reduce weeds, and provide N to subsequent crops without depleting soil moisture. Spring-planted peas had much lower biomass and more weed pressure.

 Gallagher, R. S., D. Bezdicek, and H. Hinman. 2006. *Various Strategies to Achieve Ecological and Economic Goals in the Transition Phase of Eastern Washington Organic Dryland Grain Production.* Final report for ORG project 2002-03805. CRIS Abstracts.\* Also see 2012 web log update at <http://cahnrs.wsu.edu/blog/2012/04/transitions-people-small-bites-events/>.

 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.\*

Slide 50 – *Drought resilience and water use*

 Plants can be drought resilient because they use water efficiently, needing less moisture to generate a given amount of biomass or reach desired maturity and yield (low water usage), or because they have deep, extensive root systems that can tap subsurface soil moisture reserves. Pearl millet and cowpea combine deep roots with fairly light moisture use, while field pea and medic have shallow roots and low water requirements. In contrast, the drought resilience of alfalfa, sunflower, safflower, and sainfoin are 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 increased moisture deficits and lower yields compared to crops grown after less moisture-demanding covers or fallow.

 Thus, dryland farmers need cover crops that combine drought tolerance with low water use intensity.

 The USDA Cover Crop Charts for the Northern Great Plains (updated 2018) provides information on 58 cover crops including drought and salt tolerance, moisture usage, life cycle, and N fixation and recovery. In addition to widely used species, this chart includes several less well-known cool season grasses that combine superior salt tolerance with moderate to high drought tolerance and water use efficiency: Russian wild rye, alkali grass, and several species of wheatgrass.

 Cover Crop Chart for the Northern Great Plains:

 <https://www.ars.usda.gov/plains-area/mandan-nd/ngprl/docs/cover-crop-chart/>.

 Cover Crop Chart: Common Cover Crops for California:

<https://efotg.sc.egov.usda.gov/references/public/CA/CA_CCC_with_Links_Rev_1-2018_508R.pdf>

 John Idowu and Kulbhushan Grover. 2014. *Principles of cover cropping for arid and semiarid farming systems.* New Mexico State University Extension Guide A-150, 8 pp.

 *Managing Cover Crop Profitably*, 3rd edition\*, published by USDA Sustainable Agriculture Research and Education (SARE). <http://www.sare.org/Learning-Center/Books>.

Slide 51 – *Cover crops for moisture-limited regions: California Central Valley*

 Procedure for CA trials: Soil was pre-irrigated (2 inches) in October, cover crops (mustard, two brome cultivars, triticale, burr medic, and 2 and 3-species compositions thereof) were planted on November 26, 2013 and grown with no further irrigation (rain total 6.08”, 0.43” in Dec, none in Jan, 5.65” in during Feb-Mar).

 Biomass production of ‘Cucamonga’ California brome (*Bromus carinatus*) and ‘Bracco’ white mustard (*Sinapis* alba) significantly exceeded triticale, while ‘Blando’ soft brome (B. hordaceous) had lower biomass and ‘Scimitar’ Spineless Burr Medic ( *Medicago polymorpha*) largely failed (poor germination).

 Dry weight biomass at termination was cited as near 11,000 lb/ac for Cucamonga brome, Bracco mustard, brome + mustard, and triticale + mustard (with virtually no weeds), 8,000 for triticale (which maintained the highest soil moisture as of April), 4,700 for ‘Blando’ brome, and 1,500 lb/ac plus 3,368 lb weeds/ac for burr medic.

 Margaret Smither-Kopperl, Manager and Shirley Alvarez, Biological Science Technician, USDA Lockeford, CA. *Evaluation of Drought Tolerant Cover Crops for California’s Central Valley.* Final Study Report. 7pp.

<https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/capmcsr12523.pdf>.

Slide 52 – *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.

 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.

 While cover crops may extract soil moisture in the short run, they build SOM and moisture holding capacity in the long run. Planting promptly in fall after grain harvest gives better weed control and biomass than spring planting, and terminating early enough (bud to bloom stage) can reduce moisture deficit / yield tradeoff for the following grain. Terminating later (pod set) increases moisture consumption, 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 in terms of biomass, N fixation, moisture efficiency (can terminate earlier than spring planting), and subsequent grain yields (37 vs 26 bu/ac for winter wheat after winter vs spring pea).

 Eight farms tested various high-diversity mixes, such as camelina, flax, oat, pea, radish, turnip, vetch; or buckwheat, camelina, clover (berseem), pea, safflower, turnip. Cover crops were planted between April and 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 (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% (range 3 to 58%).

 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 relative to fallow (1.8 inches), and caused moderate (9.4 bu/ac) yield losses at one site (northern MT) and no significant loss at a second site (Gallatin Valley) with better winter moisture recharge.

 Jones, C. , R. Kurnick, P. Miller, K. Olson-Rutz, and C. Zabinski. 2015 Montana Cover Crop Survey Results. Dept. of Land Resources and Environmental Sciences, Montana State University. 15 pp.

 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.msuextension.org/>.

 Miller, P., 2016. Using cover crop mixtures to improve soil health in low rainfall areas of the northern plains. Final report for Western SARE project SW11-099, 40 pp. <http://landresources.montana.edu/soilfertility/documents/PDF/reports/CCMFinalRptSW11-099Apr2016.pdf>.

 Olson-Rutz, K., C. Jones, and P. Miller. 2010. Soil nutrient management on organic grain farms in Montana. Montana State University Extension bulleting EB0200, 16 pp. <http://msuextension.org/publications/AgandNaturalResources/EB0200.pdf>.

Slide 53 – *Cover crops for moisture-limited regions: Northeast*

 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. Many of the farms have shallow, stony soils, and most of the year’s limited moisture (average 11 inches) comes in the wintertime, 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 inherent properties of many of the soils are more favorable (order Mollisols). Thus, eastern 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 during the fallow year included:

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

 Initial trials with a range of cover crops turned up some surprises: cowpea and sunnhemp 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/or soil moisture was inadequate. Field pea did well in all three planting dates, while fava bean suffered from lack of moisture, and both winter rye and hairy vetch were found to be too likely to become weeds in subsequent crops.

 Fall planted covers were often “dusted-in” and lay dormant until spring, during which weeds got the jump on them. Spring planted covers established more 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, as 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 measureable yield increases (102 – 122% of control) in about a quarter of trials. The yield response to cover crop seemed to depend on depth to moisture (DtM): the drill can set seed to about 3 – 4 inches; thus soil drying that goes any deeper interferes with germination and establishment.

 Taking soil cores during cover crop growth can inform the farmer when it is time to terminate the cover crop.

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

 *Meeting the Challenges of Soil Health in Dryland Wheat*. NRCS webinar by Leslie Michel, Oct 9, 2018. Archived at the Science and Technology Training Library archive, <http://www.conservationwebinars.net/listArchivedWebinars>.

Slide 54 – *Blade plow*

 The blade 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 and corn by 23% and 17% compared to a no-cover control, respectively, while the same cover crop terminated by disking promoted soil moisture loss and reduced soybean yields by 14%.

 In the Columbia plateau (annual precipitation <12 inches), 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.

 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> .

 Sharratt, B., and G. Feng. 2009. Friction velocity and aerodynamic roughness of conventional and undercutter tillage within the Columbia Plateau, USA. Soil & Tillage Research 105: 236 – 241.

Slide 55 – *Questions?*

\* For project proposal summaries, progress and final reports for USDA funded Organic Research and Extension Initiative (OREI) and Organic Transitions (ORG) projects, enter proposal number under “Grant No” and click “Search” on the CRIS Assisted Search Page at:

<http://cris.nifa.usda.gov/cgi-bin/starfinder/0?path=crisassist.txt&id=anon&pass=&OK=OK>.

Note that many of the final reports on the CRIS database include lists of publications in refereed journals that provide research findings in greater detail.