Soil Health and Organic Farming

Water Management and Water Quality

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ORGANIC FARMING RESEARCH FOUNDATION

SOIL HEALTH AND ORGANIC FARMING

WATER MANAGEMENT AND WATER QUALITY

An Analysis of USDA Organic Research and Extension Initiative (OREI) and Organic Transitions (ORG) Funded Research from 2002-2016

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Introduction

Managing water resources effectively during both water scarcity and periods of water excess is critical for successful farming. Moisture limitation is one of the key constraints in agricultural production, and vegetable and fruit producers often invest in irrigation infrastructure even in high rainfall (40 inches or more) environments. Efficient utilization of irrigation water is essential for production, economic, and environmental reasons, especially in regions with limited annual rainfall. In drought conditions, the major threat of inadequate water is crop failure. When surface water is unavailable, excessive irrigation from groundwater can deplete aquifers and lead to salt accumulations near the soil surface, which can harm soil life, degrade tilth, and reduce crop yields.

Excessive soil moisture can also cause problems. On well-drained soils, surplus moisture moves promptly out of the root zone, but often it carries soluble nitrogen (N) with it, reducing N availability to crops and potentially compromising groundwater quality. On slower-draining or compacted soils, surplus water runs off from sloping fields, carrying sediment and nutrients into streams. On level terrain, ponding and saturated soil conditions can occur, which increase the risk of root rots and other plant diseases, and lead to denitrification losses of plant-available N, some of which is released as the greenhouse gas nitrous oxide (N_2O). During prolonged saturation, the soil can become anaerobic, which inhibits the function of plant roots and beneficial soil organisms, and harms soil health.

Soils that become degraded by excessive tillage, overuse of agrochemicals, or insufficient plant cover or organic inputs, lose some of their capacity to sustain plant growth during dry spells and to absorb heavy rainfalls. Compaction, surface sealing, and loss of tilth (structure) hin-

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der water infiltration and reduce available pore space for holding plant-available moisture.

The recent California drought, which caused officials to declare a state of emergency from 2014 -2017, highlights the exceptional challenges farmers face from water scarcity. In the 2015 OFRF survey of organic farmers in California, the topic of drought and how farmers can manage water to ensure the survival of their operations, was the top research priority for survey respondents (Jerkins and Ory, 2016). Many growers listed the impact of the drought as their biggest production challenge. One survey respondent stated, "Weather, particularly drought issues are our most pressing concern. However, three years ago we were faced with the issues associated with drowning rain and lack of sunshine. We seem to be swinging between extremes annually. This June [2015] our weather was a 1 in 400-year drought."

The winter of 2017 brought heavy rainfall and replenished the Sierra snowpack, relieving the drought throughout most of California. However, the heavy rain caused its own challenges by flooding California's agricultural fields. As precipitation patterns have become more extreme and unpredictable across the US, research on how organic farmers can best cope with both intense drought and excessive seasonal precipitation has emerged as an important research priority.

Organic and sustainable production systems can enhance water use efficiency and reduce the need for irrigation, largely by improving and maintaining soil health. Practices like cover cropping and adding organic amendments can enhance soil health and help farmers improve water management, especially when dealing with unpredictable precipitation patterns.

Increasing soil organic matter levels and improving tilth enhances the capacity of the soil to hold plant-available moisture, and to absorb more water without becoming waterlogged or anaerobic. A network of large and smaller pores open to the soil surface and extending through the soil profile enhances moisture infiltration and storage during rainfall, so that crops can draw on existing moisture reserves during dry spells and are less apt to require frequent irrigation. Cover cropping, organic inputs, and careful tillage (no more than necessary) all contribute to the soil's capacity to absorb and store moisture for crop use and minimize runoff.

Organic farming has been shown to improve soils so that they are better equipped to cope with drought conditions. In the Rodale Institute Farming Systems Trials comparing organic and conventional corn-soy-wheat systems, higher soil organic matter and better soil structure in the organic systems enhanced moisture infiltration and storage, and improved corn grain yields some 30% during drought years (Pimentel et al., 2005; Rodale Institute, 2011). Organic practices that improve water infiltration and soil moisture storage can similarly benefit other crops (Creech, 2015; Moncada and Sheaffer, 2010; Reeve, 2014).

Organic producers in semiarid regions, include moisture limitation along with nitrogen (N), phosphorus (P), and weed management and soil quality itself, as top production constraints and research priorities (Norton et al., 2014). Dryland crop or pasture production in moisture-limited environments requires optimum efficiency in the use of water provided by natural rainfall. Growers in humid regions have cited amelioration of both deficient and excessive moisture conditions as objectives in selecting and managing cover crop mixes (Kaye, 2016; White et al., 2016).

In addition to coping with drought and flooding, both organic and conventional farmers face the challenge of reducing water pollution from nutrients. Proper water management, combined with best nutrient management practices, can decrease nutrient leaching into groundwater and runoff into surface water.

Irrigation practices and water conservation measures can, in turn, affect soil health by maintaining moisture conditions conducive to a healthy, active, and balanced soil food web. For example, proper irrigation water management can help farmers avoid soil degradation such as waterlogging, salinization, or surface crusting (resulting from overhead irrigation water drop impact on bare soil).

Cover cropping, organic inputs, and careful tillage (no more than necessary) all contribute to the soil's capacity to absorb and store moisture and to minimize runoff.

Best Management Practices for Water Management and Water Quality in Organic Production Systems

Understanding the Effects of Soil Type, Soil Texture, and Inherent Limitations

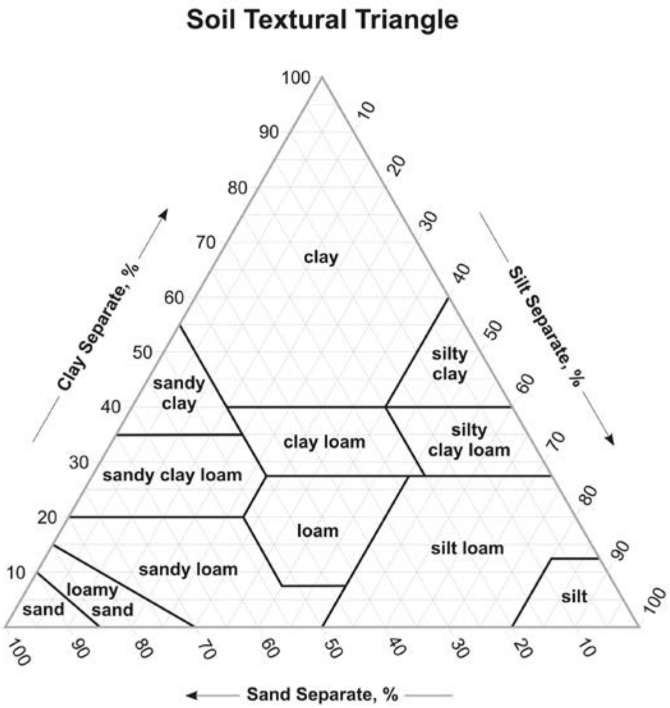

Figure 1. USDA soil texture triangle (USDA NRCS, n.d.). This soil textural triangle can be used to determine the soil textural class based on the percent composition of sand, silt, and clay.

Effective water management begins with knowledge of the soil. Use the USDA Natural Resource Conservation Service (NRCS) Web Soil Survey (Table 1, pg. 16, item 1) to identify your soil types and properties, paying particular attention to textural class, drainage class, permeability, proneness to runoff, depth to bedrock, depth to water table, and presence/absence of naturally occurring subsurface hardpans.

The texture of the soil is based on the proportions of sand, silt, and clay particles in the soil. Sand = 0.02 mm in diameter, silt = 0.002 – 0.02 mm in diameter, and clay = <0.002 mm in diameter. Textural classes (loam, sandy loam, clay loam, etc.) are defined in the USDA soil texture triangle (Figure 1). Soil texture can be determined by lab procedure or estimated by feel as described by NRCS (Table 1, pg. 16, item 2).

Texture and other inherent soil properties significantly influence a soil's capacity to absorb and store rainfall and irrigation water, and to drain sufficiently to maintain aerobic conditions in the root zone. In addition to mineral and organic materials, soil contains a network of large, medium, and small pores through which air and moisture move. Rain or irrigation water moves readily into and through soil via the larger (macro) pores, which then drain by gravity to the water table, allowing air to enter the soil. After this "gravitational water" has drained, the soil is at "field capacity," with plant-available water remaining in medium to small pores. The finest (micro) pores hold moisture so tightly that plants cannot access it ("hygroscopic water").

Coarse-textured (sandy) soils are dominated by macro-pores, and tend to have low moisture holding capacity, causing crops to be more prone to drought, especially if the subsoil (B horizon) is also sandy. Medium-textured loams and silt loams have the greatest capacity to hold plant-available water, whereas fine-textured (clayey) soils, rich in micro-pores has more hygroscopic and less plant-available moisture (Kolb, 2011). High clay content can slow drainage and infiltration, thereby intensifying runoff from sloping fields. A high water table, shallow soil profile, or naturally occurring subsurface hard layer (fragipan or duripan) can also hinder drainage regardless of topsoil texture.

Knowing your soil's inherent strengths and weaknesses regarding water relations can inform your strategy, including soil building practices to improve drainage or water retention, as well as optimum irrigation management. See Table 1, pg. 16, items 1 through 5 for more on soil texture, water relations, and implications for water management.

Improving Dynamic Soil Properties for Water Capacity: Soil Structure and Organic Matter

In most soils, water infiltration, drainage, and plant-available water holding capacity can be improved by building soil organic matter (SOM), biological activity, and overall soil health; and by addressing management-related constraints such as compaction. In order to hold and provide sufficient moisture to crops, the soil must:

- Have a sufficient network of large pore spaces open to the surface and extending throughout the profile to absorb rainfall and irrigation readily.
- Have sufficient smaller pore space to hold water in plant available form.
- Allow plant roots to penetrate throughout the soil profile so that plants can access deep moisture reserves during dry spells.

SOM plays a central role in the soil's ability to absorb, hold, and deliver plant-available water. SOM consists

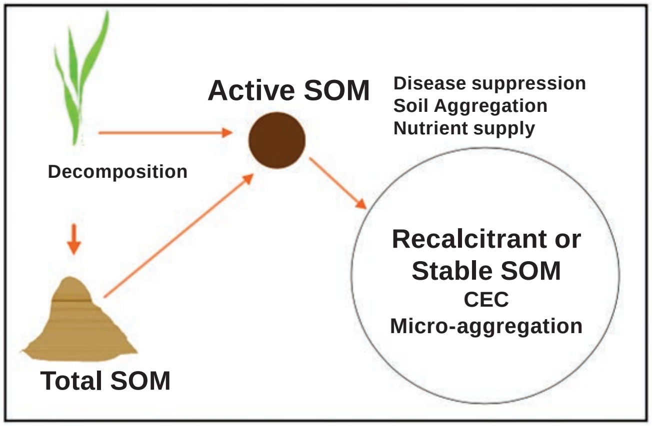

Figure 2. Components of soil organic matter, Fenton et al., 2008.

of plant and animal material in the soil that is being broken down (Fenton et al., 2008). Its components include plant residues, microorganisms, detritus, and stable organic matter consisting of elements that have been highly decomposed (Fenton et al., 2008, Figure 2). All of these components contribute to water infiltration and retention, and the stable organic matter in particular can absorb and hold six times its weight in water. Thus, incorporating organic materials like finished compost into soils with poor water holding capacity, such as sandy soils, can enhance their moisture capacity and mitigate the effects of drought (Lewandowski, 2002).

Both SOM itself and the growth and metabolic activities of soil micro-organisms enhance the soil's pore space by improving *soil structure*, the arrangement of primary soil particles (sand, silt, clay) into clumps or *aggregates*. Enhancing soil structure and aggregate stability can increase the number of macro-pores in fine-textured soils, thereby improving drainage and aeration; and the number of smaller pores in sandy soils, thus improving their moisture-holding capacity.

To increase soil organic matter with the aim of improving water holding capacity, moisture infiltration, and soil drainage, there are several steps that an organic farmer can take. These include:

- Growing crops that leave a high biomass of roots in the soil and a high biomass of surface residue, including cover crops that supply root and surface residue (Lewandowski, 2002).
- Including deep rooted and perennial crops in the rotation to build SOM, biological activity, and soil structure deeper in the soil profile and improve plant access to deep moisture.
- Applying soil amendments including manure, crop residues, straw, hay, silage, and compost to support biological processes that maintain porosity and moisture-holding capacity.
- Applying nutrients judiciously, especially N, and maintaining a balance of N-rich and C-rich materials in organic inputs.

- Reducing tillage when practical to minimize oxidation of SOM.
- Implementing management-intensive rotational grazing in livestock farming. This practice has been shown to build SOM in pasture and range, and likely improves water infiltration and moisture holding capacity.

For more information on building SOM and moisture holding capacity, see Table 1, pg. 16, items 6, 7, 8, and 9, and the companion guide *Building Organic Matter for Healthy Soils: An Overview.*

More on Compost

Compost consists of organic waste materials that have been transformed via microbial action into biologically stable organic matter. Compost is an important soil amendment for increasing water holding capacity because of the ability of stable organic matter to hold water in the soil. Some studies indicate that using compost in conjunction with cover crops can build SOM faster than cover crops alone (Delate et al., 2015), and compost has been recommended as a means to build SOM and moisture holding capacity quickly in small scale operations such as urban farms or community gardens (Cooperband, 2002). However, repeated heavy compost applications can build up excessive nutrients, especially N and P (Rom, 2013; Sanchez, 2017), which can increase risks to water quality (Cavigelli et al., 2014; Li et al., 2009).

More on Cover Crops

As noted above, cover crop roots build SOM and aggregation throughout the soil profile and thereby contribute to water holding capacity. Cover crops also conserve moisture directly by reducing runoff (USDA NRCS, n.d.), relieving compaction, and enhancing water infiltration into the soil. However, as living plants that transpire moisture, cover crops can reduce soil moisture content during and for a period of time after their growth cycle. In times of ample or excessive moisture, this can benefit the farming operation (e.g., a winter rye + vetch cover crop helps dry out the soil during a wet spring to allow timely planting of corn, soybean, or summer vegetables). In a drought year, or in regions with limited rainfall, a vigorous, deep rooted cover crop can leave insufficient moisture in the soil profile for the following production crop (Baenziger et al., 2010; Shapiro et al., 2014; White et al, 2016). In drier regions, cover crop species and variety, and timing of cover crop planting and termination need to be selected carefully to leave sufficient moisture for the production crop. In the long run, the benefits of improved tilth, soil structure, and surface cover may outweigh the use of moisture by cover crops.

For more information, see Table 1, pg. 16, items 3, 4, and 10, and the companion report, *Cover Crops: Selection and Management*

Conserving Moisture: Mulching, Weed Control, and Irrigation Management

Keeping the soil covered by surface residues or organic mulch reduces evaporative losses of moisture from the soil surface. Permeable organic mulches allow rain or irrigation water to enter the soil, and then slow evaporation by keeping the soil surface cooler and protecting it from direct exposure to sun and wind. For example, in Virginia, hay mulch enhanced surface soil (0-12 inches) moisture levels during dry spells by 10 to 50 g/kg compared to bare soil, and improved tomato yields in three out of four site-years (Schonbeck and Evanylo, 1998).

Mulching can also help reduce weed competition against the crop. Because weeds reduce crop yields in large part by consuming precious soil moisture, effective weed control helps conserve moisture. Integrated weed management that utilize mulches, crop rotation, and cover crops to reduce reliance on tillage and cultivation is an integral part of sustainable soil and water management.

Plastic film mulches retain soil moisture and, when laid over drip irrigation tape, can optimize irrigation efficiency. Superior water management and weed control, combined with soil warming that enhances yield and earliness in tomato and other warm season crops, make plastic the mulch-of-choice for many organic producers. However, plastic films exclude natural rainfall, can limit soil aeration, do not feed soil life, and must be removed and discarded at the end of the season. Landscape fabric is a water permeable synthetic mulch that admits rainfall into the soil, provides weed control similar to plastic film, and is sturdy enough to reuse for up to 10 seasons.

Efficient use of irrigation water is essential, especially in low rainfall regions such as the Great Plains and Intermountain West. Over-irrigation wastes energy as well as the water resource itself, and can lead to increased ponding, runoff, and/or leaching, with attendant nutrient loss and nutrient pollution of ground and surface water. In-row drip irrigation optimizes water use efficiency by delivering moisture directly into the crop root zone without watering inter-row weeds or losing moisture to evaporation as can occur with overhead irrigation. Because it does not wet foliage, drip irrigation also helps prevent the spread of foliar plant diseases in crops such as blueberry (Strik et al., 2015) and many vegetables. Drip irrigation is the method of choice for many smaller-scale horticultural producers, but is usually not practical for larger-acreage production of agronomic crops.

- Some practices to conserve soil moisture and optimize irrigation efficiency include:
- Maintain soil coverage with crop residues or mulch to reduce evaporative losses.
- Limit water use by weeds through an integrated weed management strategy.
- Use in-row drip irrigation under organic or plastic mulch where practical.
- Monitor field moisture, weather, and crop condition; and use available decision tools to optimize timing, amount, and frequency of irrigation.
- Build soil health as described above to reduce the amount and frequency of irrigation needed (see Case Study, Park Farm Organics).

Case Study

Figure 3. Tomatoes grown at Park Farm Organics.

Research funded by OFRF, conducted by Dr. Amélie Gaudin of University of California, Davis, and organic farmer and research collaborator Scott Park of Park Farm Organics, has shown promising results with soil building practices to allow decreased water use. The ongoing project examines whether soil health building management practices (e.g., diverse crop rotation, cover cropping, compost, conservation tillage, controlled traffic) implemented by Scott Park will improve water use efficiency for the production of processing tomatoes (Figure 3). Researchers compared a regular irrigation schedule with a deficit schedule that advanced irrigation cutoff to 45 days before harvest. The researchers found that the deficit irrigation implemented saved 0.5 ac/feet of irrigation water and increased water use efficiency by 19% with no significant effect on yield and plant development. The organically improved soil apparently enhanced deep moisture storage. The study will continue for a second year to confirm these initial findings and to develop recommended soil health/irrigation co-management strategies for organic farms in Northern California. For more information please see the video at https://www.youtube.com/watch?v=yapM4_SUu6I

Addressing Salt Problems in Low-Rainfall Regions and in High Tunnels

In regions where annual evapotranspiration rates exceed annual rainfall, the use of groundwater for irrigation can build up salts in the topsoil, leading to stress on the soil life, salt injury to crops, and reduced yields. The same circumstances can occur in high tunnels regardless of the climate, because rainfall is excluded from the structure. The salt issue creates a bit of a paradox: on the one hand, the less irrigation water applied, the less salt is potentially deposited; on the other, the standard remedy for an existing salt buildup is application of sufficient water to affect a net downward leaching of salts out of the crop root zone (Brady and Weil, 2008).

In high tunnel production, careful nutrient management is needed to prevent salt buildup. Soil salinity (electrical conductivity or EC) needs to be monitored, especially when compost is applied heavily (1 inch depth or more) (Sanchez, 2017). Excess salts can be leached by applying 6 inches or more of irrigation water, or leaving the high tunnel beds open to natural rainfall for several months (Sanchez, 2017). Some additional tips include:

- Using low-salt nutrient sources when practical (poultry litter products are fairly high salt).
- Avoiding over application of nutrients, including compost.
- Testing irrigation water for salts and using high quality (low salt) water, if available.
- Collecting high tunnel roof runoff for irrigation (rainfall is very low in salts).
- Managing for low soluble N (reduce inputs, grow heavy N feeder) in order to protect groundwater quality during the weeks prior to leaching to remove salts.
- Building soil health as outlined earlier to reduce the need for irrigation and nutrient inputs.

Tillage Practices and Water Management

The less the soil surface is disturbed, the more macropores remain open to the surface to allow rainfall and irrigation water to enter easily. Conservation tillage practices ranging from no-till and minimal tillage, to mulch tillage (leaving ≥30% residue coverage), contour tillage, and ridge tillage, can increase the capacity of the soil to store water (Busari et al., 2015). In loamy sand and sandy loam soils, the use of cover crops in conjunction with reduced tillage can increase water infiltration by as much as 30-45 percent when compared to conventional tillage (Hawkins et al., n.d.).

- Reducing tillage also protects soil life and SOM. Although continuous no-till is not practical for organic production of annual crops, producers can take steps to enhance water management through careful tillage, including:
- Reducing the frequency and intensity of tillage and cultivation whenever practical.
- Avoiding tilling when soil is too wet (causes compaction) or too dry (pulverizes aggregates).
- Choosing implements that lessen fragmentation of soil aggregates. For example, spading machines leave soil structure more intact that plow-disk or rotary tillage.
- Terminating some cover crops without tillage (e.g., roll-crimping, or by winterkill).
- Tilling shallowly (1-2 inches) when practical, using a rotary harrow or other suitable implement.
- Using mulch tillage, leaving at least 30% coverage by residues.

Avoiding deep tillage at the end of a production or cover crop's growing period leaves plant root to decay undisturbed in the soil profile. This creates channels that facilitate moisture infiltration and root growth of the next crop. For example, the large, deep channels left by winterkilled tillage radish greatly enhance infiltration and reduce runoff from winter rains, and improve rooting depth and grain yields in corn and soybeans (Gruver et al, 2016).

Additional Measures to Prevent and Remedy Soil Compaction and Crusting

Compacted soils with little organic matter and few large pore spaces (macropores) make it difficult for water to infiltrate into the soil, resulting in ponding in level fields and increased runoff from sloping fields. Improving the soil structure by increasing macropore spaces between aggregated soil clumps allows water to infiltrate the soil more easily (Kolb, 2011). Compacted soils become waterlogged and anaerobic more easily during times of excessive rainfall. Yet, they also have less total pore space, and thus lower capacity to store plant-available moisture and sustain crops during drought. A subsurface plowpan or tillage hardpan can slow drainage of excess (gravitational) water from the topsoil and restrict plant root access to deeper moisture reserves. Some steps farmers can take to relieve soil compaction include:

- Amend soils as needed to address any nutrient- or pH-related constraints on crop growth, using materials allowed by the USDA National Organic Program (NOP).

- Use targeted tillage to physically relieve severe compaction or hardpan, e.g., chisel plow to a depth 1 – 2 inches below the bottom of a plowpan.
- Immediately after tillage, plant a "subsoiling" cover crop with deep, robust root systems, such as tillage radish, sorghum-sudangrass, or biennial sweetclover. Combining taprooted and fibrous-rooted species may be most effective.

Figure 4. Soybean seedlings emerging through a crusted soil, University of Minnesota Extension

To prevent soil compaction and maintain surface and subsurface porosity and water permeability, it is advisable to:

- Reduce tillage as described on pages 11-12.
- Choose least-compacting tillage tools, such as the spading machine or chisel plow.
- Avoid tilling, driving, or walking in the field when the soil is wet.
- Avoid compacting the soil with heavy machinery or overgrazing.
- Use permanent raised beds or other controlled-traffic system to eliminate all traffic from production beds or grow zones.
- Maintain living plant cover and living roots in the soil profile year round.
- Continue soil building practices described on page 5.

One form of compaction is soil crust or surface crust. A soil crust is a thin layer of surface soil which becomes more compacted and impermeable than the soil below (Figure 4).

Soil crusts usually occur when heavy rains or overhead irrigation pound the soil after tillage or cultivation has fragmented soil surface aggregates into individual soil grains (sand, silt, clay). The pulverized soil then sticks together in solid masses when direct sun dries the soil after. Fine-textured soils are more prone to crusting than sandy soils, and any soil that is low in SOM and poorly aggregated crusts more readily. Soil crusts prevent or hinder the emergence of crop seedlings from the soil (Figure 4). Soil crusts also hinder infiltration of subsequent rainfalls into the soil, which leads to runoff and reduces storage of plant-available water. Practices that help to prevent soil crusts include:

- Reduce tillage as much as practical
- Use integrated weed management to lessen the need for cultivation.
- Build SOM with compost and other organic inputs.
- Keep the soil covered with living vegetation, residues, or organic mulch (protects the surface and encourages soil biological activity that maintains soil aggregation).
- Landscape fabric and plastic film mulches provide some protection from crusting compared to exposed bare soil, but they do not feed soil life
- Use in-row drip irrigation or mist irrigation in lieu of overhead irrigation. For overhead irrigation, drop nozzles are gentler and less compacting than impact nozzles.

For more information on reducing tillage in organic production systems, see the companion guide *Practical Conservation Tillage.*

Conservation Practices to Prevent Runoff and Erosion, and Protect Water Quality

Excessive water runoff from farmland can lead to soil erosion and pollution of water with soluble nitrogen (N), phosphorus (P), and sediment. Similarly, water that leaches below the root zone can degrade groundwater quality, mainly with nitrate-N and (especially in conventional agriculture), pesticides, and herbicides. The soil health and water management practices outlined above can help protect water resources. For example, cover crop roots recover leached nutrients, thereby protecting water quality and enhancing fertility for the following crop. Winter cover crops are considered vital for reducing runoff from fields and attendant contamination of surface water resources (USDA NRCS, n.d., Cahn et al., n. d.). Keeping the soil 100% covered with plant residues can virtually eliminate runoff and erosion (Magdoff and van Es, 2009) and organic farming methods that rely on compost and legume cover crops for N have reduced nitrate-N leaching by nearly

50% compared to conventional (Delate et al., 2014).

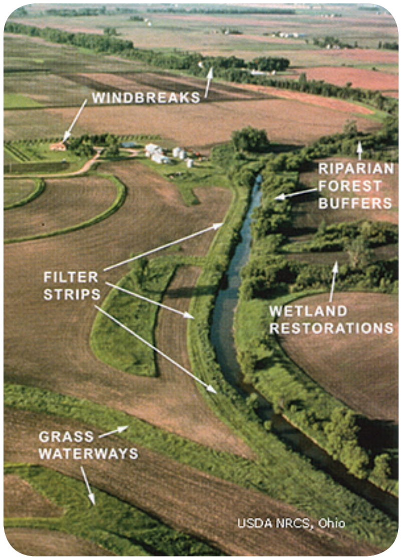

Figure 5. Grass waterways and filter strips are part of a conservation effort to reduce erosion and runoff (Photo from USDA NRCS, Ohio) https://www.mda.state.mn.us/protecting/conservation/practices/buffergrass.aspx

Even the best water and soil management will not eliminate all runoff and leaching. In hilly regions, areas of high risk for run-off can be protected by planting contour buffer strips and grass waterways to allow excess water to leave fields without causing erosion, and filter strips and buffer zones along waterways to protect water quality (Figure 5).

Filter strips and grassed waterways act by slowing down water and allowing sediment and pollutants to get trapped before entering the river or stream.

Some leaching of moisture from well-drained sandy soils during heavy rainfall or irrigation is inevitable. In these conditions, extra care is needed to avoid excessive amounts of soluble N in the soil profile. Organic nutrient management strategies that enhance the role of plant roots and soil microorganisms in retaining and cycling nutrients can promote "tight nutrient cycling" and thereby keep nitrate-N from reaching groundwater (Jackson and Bowles, 2013).

Another concern with excess water is denitrification, which can convert soluble N (nitrate-N and ammonium-N) into nitrous oxide (N_2O), a powerful greenhouse gas with 300 times the warming potential of CO_2. N_2O emissions occur at times of high levels of soil moisture (~80% of total pore space water filled), soluble and/or readily mineralizable organic N, active organic C, and microbial activity occur together (Cogger et al., 2014). Such emissions often occur in brief intense bursts (minutes to hours) after an event such as heavy rainfall or incorporation into the soil of synthetic N fertilizer or N-rich organic materials like poultry litter (Baas et al., 2015).

Environmental risks related to N during periods of excess moisture can be minimized by the following strategies:

- Manage N carefully, and avoid applying surplus N.
- Use a diversity of organic inputs that include both low and high carbon: nitrogen (C:N) ratio materials, to promote tight nutrient cycling (Jackson and Bowles, 2013).
- Combine low C:N cover crops (legumes, crucifers) with high C:N species (grasses).
- Allow cover crops to grow a couple weeks longer to consume a short-term water excess.
- Maintain good infiltration, drainage, and moisture holding capacity through the soil health practices outlined earlier.

For more on nutrient management see the companion guide, *Nutrient Management for Crops, Soil, and the Environment.*

Table 1: Information Resources on Water Management on Organic Farms:

1. **NRCS Web Soil Survey**. Soil series, texture, and any inherent constraints such as naturally occurring hardpans, limited or excessive drainage, stoniness, limited depth to bedrock, and erodibility. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

2. **NRCS Guide to Texture by Feel, and Texture Class diagram**. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311.

3. **Building Soils for Better Crops**, 3rd ed. (Magdoff, F. and van Es, H. 2009). Sustainable Agriculture research and Education (SARE). http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition

4. **Comprehensive Assessment of Soil Health: The Cornell Framework**.Edition 3.1. Cornell University, Geneva, NY. 123 pp. Manual provides information on how soil organic matter and soil health affect soil functions including moisture infiltration, water holding, and drainage; and a protocol for measuring water holding capacity. Available at http://soilhealth.cals.cornell.edu/training-manual/

5. **Soils and Water Availability**. (Peter Kolb, 2011) eXtension bulletin that outlines the relationship between soil texture and other properties and moisture holding capacity. http://articles.extension.org/pages/33617/soils-and-water-availability

6. **The Farming Systems Trial: Celebrating 30 Years**. (Rodale Institute, 2011).13 pp. https://rodaleinstitute.org/our-work/farming-systems-trial/farming-systems-trial-30-year-report/.

7. **Soil Organic Matter Fact Sheet**. (Fenton, M., Albers, C., and Ketterings, Q. 2008.) http://franklin.cce.cornell.edu/resources/soil-organic-matter-fact-sheet

8. **Building Soil Organic Matter with Organic Amendments. A resource for urban and rural gardeners, small farmers, turfgrass managers and large-scale producers**. (L. Cooperband, 2002.) University of Wisconsin-Madison, Center for Integrated Agricultural Systems, September 16, 2002. https://www.cias.wisc.edu/wp-content/uploads/2008/07/soilorgmtr.pdf

9. **Organic Matter Management**. (A. Lewandowski, 2002) https://www.extension.umn.edu/agriculture/soils/soil-properties/soil-management-series/organic-matter-management/

10. **Cover Crops - Keeping Soil in Place While Providing Other Benefits**. (NRCS) https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ny/technical/?cid=nrcs144p2_027252

11. **Dealing with High Soluble Salts in High Tunnels**. (Elsa Sanchez, Pennsylvania State University Extension), 2 pp. http://extension.psu.edu/plants/vegetable-fruit/fact-sheets/salts-in-high-tunnels/dealing-with-high-soluble-salt-levels-in-high-tunnels.

What is the Current Science on Soil and Water Management for Organic Systems: An Analysis of USDA OREI and ORG Funded Projects from 2002-2017

Water Management Benefits Of Cover Crops And Other Organic Management Practices

The benefits of cover cropping, compost, crop rotations with a perennial sod phase, and other best organic management practices, including enhanced SOM, soil structure, and biological activity, have been extensively documented (Delate et al., 2015; Gallagher et al 2006; Jackson and Bowles, 2013). Practical manuals on organic soil management cite moisture infiltration and water holding capacity as key benefits of building SOM and soil health (Magdoff and van Es, 2009; Moncada and Sheaffer, 2010), and cover crops have been recommended for intercepting runoff in strawberry production in California (Cahn et al., n.d.). However, few organic agricultural studies have published hard data on the impact of these practices on soil moisture holding capacity. In Florida, rotating organic vegetable fields into bahiagrass for two or more years improved SOM and was reported to reduce water and nutrient requirements of subsequent production crops (Andersen et al. 2014), and the use of organic mulch conserved soil moisture during dry spells in tomato production in Virginia (Schonbeck and Evanylo, 1998).

Minimizing soil disturbance can improve soil moisture holding capacity. For example, a period of no-till management has been recommended to build SOM for subsequent crop production in low rainfall regions (Norton et al., 2014). In an organic farm case study in the Central Valley of California, soil surface water infiltration rates were 230% higher in hedgerows and riparian buffers (undisturbed perennial cover) than in adjacent production fields (Jackson et al., 2008).

Organic practices and improved crop rotation can protect water quality. In corn and soybean farming system trials, organic fertility management reduced nitrate-N leaching to groundwater compared to the conventional system, and including cereal grains or perennial sod (pasture) in the rotation further reduced N leaching (Delate et al., 2014). Best organic practices that balance high- and low-C:N organic inputs and cover crops have also been shown to reduce N leaching in organic tomatoes in California (Jackson and Bowles, 2013).

Experimental breeding lines of perennial wheat developed three times the root mass as conventional wheat and virtually eliminated N leaching to groundwater (Snapp and Swinton, 2013). However, soil moisture deficits during severe drought limited the capacity of the perennial wheat to regrow the following season.

Researchers at the University of Illinois found that long term use of synthetic soluble N fertilizers causes net declines in SOM, soil organic N, and the soil's capacity to mineralize N from organic matter (Mulvaney et al., 2009). Although N fertilizer enhanced yields of grain corn and other crops, resulting in increased residue biomass return to the soil, it also stimulated microbial activity that led to a net loss of SOM through respiration. This trend was documented in the Morrow plots in Illinois (the oldest long-term farming systems trial in the US, launched in 1876), and in dozens of other farming system trials around the world (Mulvaney et al., 2009). One notable effect of this decline in SOM, also observed by farmers, is a decline in the soil's capacity to absorb and hold plant-available moisture (Philpott, 2010). Heavy use of N-rich organic amendments with a low C:N ratio have also resulted in lower SOM and less desirable soil physical properties than higher C:N amendments (Cogger et al., 2013).

Water Management Challenges with Cover Crops

While cover cropping generally improves the soil's capacity to hold plant-available water, the cover crop itself consumes soil moisture through transpiration to a degree related to its biomass and duration of active growth. As a result, the following production crop may suffer from a lack of sufficient moisture, especially in semiarid regions such as the Great Plains, Southwest, and interior Pacific Northwest. The water-related tradeoff between crop yield and soil benefits from cover cropping has emerged as a research priority for organic dryland grain producers (Creech, 2015).

The long term soil benefits of cover crops and sod crops were illustrated in a study of organic transition strategies for dryland wheat production in eastern Washington. Rotations that emphasized perennial forages and green manures during the three-year transition period reduced weed competition and gave the highest spring wheat yields (55 – 65 bu/ac) in year 4, the first year of certified organic production (Gallagher et al., 2006). Similarly, including alfalfa in the crop rotation improved SOM and organic corn grain yield compared to a simple corn-soy rotation in a lower-rainfall region of Minnesota (Sheaffer et al., 2007).

In Nebraska, integrating clover cover crops into an organic corn-soy-wheat rotation showed potential to improve yield and quality of all three crops, although risks of soil moisture depletion in dry years were also noted (Shapiro et al., 2014). Earlier trials showed much higher corn and soybean yields after a cover crop that was winterkilled (e.g., berseem clover, buckwheat, oats, soybean, sudangrass) or terminated in early spring by disking, than after roll-crimped cover crops (rye, triticale, hairy vetch), which regrew somewhat and competed for moisture (Glett et al., 2011; Shapiro et al., 2009). Winter wheat yielded better after summer fallow than after a summer green manure because the former treatment left more moisture available to establish the wheat crop (Baenziger et al., 2010).

In Montana, winter pea used moisture more efficiently than other legumes, and performed best as a green manure for a subsequent wheat crop "due to soil water conservation and N cycling" (Miller et al., 2009). The pea crop was successfully terminated by roller-crimper at the "plump pod stage," thereby protecting soil surface quality and porosity. Winter pea green manures also performed much better than the same crop planted in spring in eastern Washington (Gallagher et al., 2006). Shallow-rooted covers such as Laramie annual medic (Baenziger et al., 2010), black medic and sweet alyssum (Reeve, 2014) may also provide soil surface protection and other cover crop benefits in semiarid regions without excessively depleting deep soil moisture reserves.

Cover crops can also pose water management challenges in higher rainfall regions such as the Northeast. In abnormally dry years, water consumption by a preceding cover crop can reduce production crop yield, and the risk increases with the length of time that the cover crop is growing (White et al., 2016). However, during times of water excess and flooding, cover crops can use excessive soil moisture and allow farmers quicker entry into fields (White et al, 2016). Cover crop residue left on the soil surface as a mulch keeps soils cooler and retains moisture, which can delay production crop planting during wet years, but can benefit production during dry years (White et al., 2016). These results indicate a need for flexibility in cover crop management (termination date and method) depending on weather conditions and rainfall.

Orchard Floor Management

Horticultural crop production in dry regions requires careful water management. In a study of orchard floor management in Utah, systems that employed grass or legume alleys with straw mulch or shallow-rooted living mulch (alyssum) in tree rows were compared to a tilled fallow or landscape fabric in tree rows. Overall water use did not differ significantly among treatments, and the tilled fallow had higher bulk density (compaction), poorer soil structure, and lower SOM and microbial activity than the treatments with either living plant or organic mulch cover (Reeve, 2014; Rowley et al., 2012). This suggests that improved soil health and moisture capacity compensated for moisture utilization by the living cover.

Ground management practices had substantial impacts on root zone water availability and cherry tree growth in high tunnel fruit production in the Great Lakes region (Lang, 2014). Moisture availability and tree growth were best under season-long weed barrier (landscape fabric) or spring weed barrier plus a summer (post-harvest, post-shoot elongation) cover crop of sorghum-sudangrass. Other ground management treatments that included living vegetation during spring (mowed weeds, winter rye + hairy vetch, perennial grass + white clover) reduced soil moisture in spring by about 20% and tree growth by about 15 to 27% (Lang, 2014).

Irrigation Management

Shallow-rooted horticultural crops are especially sensitive to water management. For example, blueberry can suffer root rot from overirrigation, and drought stress during deficits. In-row drip irrigation is strongly recommended to facilitate optimum water application and reduce risks of foliar diseases (Strik et al., 2015). Although sawdust mulch may require other amendments to compensate for N tie-up (Strik et al., 2015), it has also been found to promote greater root growth than weed mat (landscape fabric), and thereby reduces the need for irrigation (Strik et al., 2011). In-row drip is also recommended for blackberry production; however, post-harvest irrigation was found unnecessary to sustain blackberry yields in Oregon (Strik et al., 2014). Omitting post-harvest irrigation saved some 67,000 gallons/acre (~2.5 acre-inches) of irrigation water and sometimes improved winter hardiness.

In an organic farm case study in California, irrigation tailwater ponds reduced sediment in irrigation runoff by 97%; however, the ponds and drainage ditches were the primary sources of N_2O emissions on the farm (Jackson et al., 2008).

Plant Genetics

Plant breeding and cultivar selection criteria for organic systems include drought tolerance (water use efficiency, reduced need for irrigation) as well as N use efficiency (facilitating N management for water quality) and competitiveness toward weeds (allowing crops to utilize a higher percentage of rainfall and irrigation water). Crops that organic plant breeding teams have selected for drought tolerance include soybean (Orf et al., 2016), barley (Murphy, 2017), corn (Goldstein, 2015), and quinoa (Murphy, 2013). Selection for N use efficiency has included corn (Goldstein, 2015), wheat (Jones et al., 2011; Worthington et al, 2015), and dry bean (Heilig and Hill, 2014). Considerable progress has been made in selecting for weed competitiveness in wheat (Baenziger et al., 2012; Kucek and Sorrells, 2016; Murphy et al., 2008; Worthington et al., 2015), carrot (Simon et al., 2016), field corn (Goldstein, 2016), soybean (Orf et al., 2016; Place et al., 2011a, 2011b), and rice (Zhou, 2016).

Water Management and Nitrous Oxide Emissions

Several studies have demonstrated an increased risk of N_2O emissions when soil moisture levels are high, such as after heavy rainfalls (Baas et al., 2015, Carpenter-Boggs et al., 2016), during the mild, rainy winters of California (Muramoto et al., 2015), or under a high biomass cover crop residue(Yarwood, 2016). The link between soil moisture and N_2O appears sufficiently robust to include this factor in simulation models for this greenhouse gas (Drinkwater and Walter, 2015).

Organic field generally emit less N_2O than conventionally fertilized cropland (Reinbott, 2015, Cavigelli, 2010), except when organic amendments with readily available N and low C:N ratios, such as poultry litter or succulent legume green manure, are used as the primary source of N (Baas et al., 2015; Li et al., 2009). While producers cannot control rainfall patterns, they can reduce risks significantly by managing N carefully and avoiding over-irrigation or ponding of irrigation tailwater, especially when conditions favor rapid N mineralization by the soil life.

Questions for Further Research in Water Management in Organic Farming

Research shows that organic practices have long term benefits for soil health, and in coping with both water scarcity during drought and water wet years. However, these practices and their impacts on water availability are nuanced depending upon regional climate and soil conditions. The topic of soil and water is crucial to all farmers, and it is an area which requires special focus and research prioritization.

A need for additional research into water management clearly exists, especially for organic dryland production in low-rainfall regions. While a number of USDA funded organic research projects have explored cover cropping, crop rotation, crop-livestock integration, reduced tillage, and other organic production practices in the Great Plains and interior Pacific Northwest, few have reported findings or provided farmer guidelines regarding soil moisture-holding capacity and water management.

Some specific areas for additional research include:

- Developing region-specific water management practices for organic systems.
- Resolving the tradeoff between long term soil health benefits of cover crops and short term water consumption by cover crops, especially for low-rainfall regions.
- Identifying crop rotations and cover crop species and cultivars best suited for water management in different regions. For example, semiarid regions need cover crops that are highly water efficient and do not deplete soil moisture reserves essential for the following crop.
- Characterizing the impact of different organic tillage regimes on soil moisture availability, including practical approaches to conservation tillage in organic systems.
- Breeding regionally-adapted crops for water and nutrient use efficiency, and capacity to enhance soil health.
- The role of soil microbial communities in soil water holding capacity, nutrient cycling, and water quality.
- Researching and refining best nutrient, water, and salt management practices for high tunnel production.
- Researching organic systems for coping with precipitation extremes for regions experiencing climate change.

References

Andersen, P. C., D. L. Wright, R. F. Mizell III, J. J. Marois, S. M. Olson, D. D. Treadwell, A. R. Blount, J. E. Funderburk, J. R. Rich, V. H. Richardson, C. Mackowiak, and G. Boyhan, 2014. *Environmental and Economic Costs of Transitioning to Organic Production via Sod-Based Rotation and Strip-Tilling in the South Coastal Plain*. Proposal and final report for ORG project 2011-03958. CRIS Abstracts.*

Baas, D. G., G. P. Robertson, S. R. Miller, N. and Millar, N. 2015. *Effects of Cover Crops on Nitrous Oxide Emissions, Nitrogen Availability, and Carbon Accumulation in Organic versus Conventionally Managed Systems*. Final report for ORG project 2011-04952. CRIS Abstracts.*

Baenziger, P. 2010. *Developing Small Grain Cultivars and Systems Optimally Suited for Organic Production*. 2010 progress report for OREI project 2007-01437.

Baenziger, P. 2012. *Developing Small Grain Cultivars and Systems Optimally Suited for Organic Production*. Final report for OREI project 2007-01437. CRIS Abstracts.*

Brady, N. C., and R. R. Weil. 2008. *The Nature and Properties of Soils,* 14th Edition. Pearson Education, Inc., Upper Saddle River, NJ. 992 pp.

Burke, I. C. E. P. Fuerst, R. T. Koenig, K. Painter, D. Roberts, D. Huggins, A. M. Fortuna, S. Machado, B. K. Baik, J. Goldberger, J. Johnson-Maynard. 2014. *Sustainable Dryland Organic Farming Systems in the Pacific Northwest*. Final report for OREI project 2009-01416. CRIS Abstracts.*

Busari, M A., Kukal, S., Kaur, A., Bhatt, R., Dulazli, A. 2015. *Conservation Tillage Impacts on Soil, Crop and the Environment*. International Soil and Water Conservation Research. Vol 3, Issue 2, Pgs. 119-129.

Cahn, M., M. Bolta, and R. Smith. n.d. *Winter Cover Crops for Reducing Storm Run-off and Protecting Water Quality in Strawberries*. http://cemonterey.ucanr.edu/files/171012.pdf

Carpenter-Boggs, L., D. Granatstein, and D. Huggins. 2016. *Greenhouse Gases and Agriculture: Where does Organic Farming Fit?* (Webinar). http://articles.extension.org/pages/30835/greenhouse-gases-and-agriculture:-where-does-organic-farming-fit-webinar.

Cavigelli, M. 2010. *Impact of Organic Grain Farming Methods on Climate Change* (Webinar) http://articles.extension.org/pages/30850/impact-of-organic-grain-farming-methods-on-climate-change-webinar.

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.*

Cogger, C, A. Fortuna, and D. Collins. 2014. *Why the Concern about Nitrous Oxide Emissions?* Webinar 1 at: http://articles.extension.org/pages/70280/two-part-webinar-series-on-greenhouse-gas-emissions-and-soil-quality-in-long-term-integrated-and-tra.

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.*

Cooperband, L. 2002. *Building Soil Organic Matter with Organic Amendments*. A resource for urban and rural gardeners, small farmers, turfgrass managers and large-scale producers. University of Wisconsin-Madison, Center for Integrated Agricultural Systems, September 16, 2002. https://www.cias.wisc.edu/wp-content/uploads/2008/07/soilorgmtr.pdf.

Creech, J. E. 2015. *Compost Carryover and Cover Crop Effects on Soil Quality, Profitability, and Cultivar Selection in Organic Dryland Wheat*. Proposal and first year progress report for OREI project 2014-05324. CRIS Abstracts.*

Delate, K., C. Cambardella, C. Chase, and R. Turnbull. 2015. *A Review of Long Term Organic Comparison Trials in the US*. Sustainable Agricultural Research 4(3): 5-14.

Delate, K., C. Cambardella, D. Jaynes, T. Sauer, R. Malone, and C. Chase. 2014. *Enhancing Farmland Water Quality and Availability through Soil-Building Crop Rotations and Organic Practices.* Final report for ORG project 2009-05499. CRIS Abstracts.*

Drinkwater, L. E., and M. T. Walter. 2014. *Optimizing Cover Crop Selection and Management to Enhance Agronomic and Environmental Services in Organic Cropping Systems.*Project proposal and progress report for ORG project 2012-02980. CRIS Abstracts.*

Fenton, M., Albers, C., and Ketterings, Q. 2008. *Soil Organic Matter Fact Sheet*. http://franklin.cce.cornell.edu/resources/soil-organic-matter-fact-sheet

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/.

Glett, D.W., C. Shapiro, S. Knezevic, E. Sarno, M. Mainz, L. Junck. 2011. *Soybean and Corn Growth as Influenced by Methods for Controlling Previous Cover Crop, Including Winter Kill, Flaming, Disking, and Crimping*. Poster presented at 2011 ASA-CSA-SSSA International Conference, October 2011.

Goldstein, W. 2015. *Breeding Corn for Organic Farmers with Improved N Efficiency/N Fixation, and Protein Quality*. Proceedings of the Organic Agriculture Research Symposium

LaCrosse, WI February 25-26, 2015. http://eorganic.info/node/12972

Goldstein, W. 2016. *Partnerships between Maize and Bacteria for Nitrogen Efficiency and Nitrogen Fixation*. Bulletin 1. Mandaamin Institute, Elkhorn, Wisconsin, 49 pp. http://www.mandaamin.org/about-nitrogen-fixing-corn.

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.

Hawkins, G., Sullivan, D., and Truman, C. n.d. *Water Savings Through Conservation Tillage*.

https://www.ars.usda.gov/ARSUserFiles/60480500/WaterSavingsThroughConservationTillage.pdf

Heilig, J., and E. Hill. 2014. *Breeding Efforts and Cover Crop Choices for Improved Organic Dry Bean Production Systems in Michigan*. http://articles.extension.org/pages/70357/breeding-efforts-and-cover-crop-choices-for-improved-organic-dry-bean-production-systems-in-michigan.

Jackson, L. and T. Bowles. 2013. *Researcher and Farmer Innovation to Increase Nitrogen Cycling on Organic Farms* (Webinar). http://articles.extension.org/pages/67391/researcher-and-farmer-innovation-to-increase-nitrogen-cycling-on-organic-farms-webinar.

Jackson, L. E., K. Klonsky, and K. M. Scow. 2008. *Nutrient Dynamics, Soil Biota, and Functional Biodiversity at an Organic Farm*. Final report for OREI project 2004-05207. CRIS Abstracts.*

Jerkins, D, and J. Ory. 2016. *2016 National Organic Research Agenda: Outcomes and Recommendations from the 2015 National Organic Farmer Survey and Listening Sessions*. Organic Farming Research Foundation (www.ofrf.org), 128 pp.

Jones, S. S., B. K. Baik, L. Carpenter-Boggs, L., and B. J. Goates. 2011. *Developing Wheat Varieties for Organic Agricultural Systems*. Final report for ORG project 2006-02057. CRIS Abstracts.*

Kaye, J. 2016. *Making Diversity Functional: Farm-tuning Cover Crop Mixtures to Meet Grower Needs*. Proposal and first-year progress report for OREI project 2015-07433. CRIS Abstracts.*

Kolb, Peter. 2011. *Soils and Water Availability*. eXtension. http://articles.extension.org/pages/33617/soils-and-water-availability

Kucek, L. K., and M. F. Sorrells. 2016. *Designing an Organic Wheat Breeding Program for the Northeast United States*. Pp. 32-36 in *Proceedings of the 8th Organic Seed Growers Conference* February 4 - 6, 2016, Corvallis, OR. http://seedalliance.org/publications#publication_category_title_13.

Lang, G. 2014. *Holistic Integration of Organic Strategies and High Tunnels for Midwest/Great Lakes Fruit Production*. Final report for OREI project OREI 2010-01905. CRIS Abstracts.*

Lewandowski, A. 2002. *Organic Matter Management*. https://www.extension.umn.edu/agriculture/soils/soil-properties/soil-management-series/organic-matter-management/

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.

Magdoff, F. and van Es, H. 2009. *Building Soils for Better crops, 3rd ed. Sustainable Agriculture research and Education* (SARE). http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition

Miller, P., 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 ORG 2005-04477. CRIS Abstracts.*

Moncada, K., and C. Sheaffer, 2010. *Risk Management Guide for Organic Producers*. University of Minnesota. 300 pp. Chapter 13, Winter Cover Crops. http://organicriskmanagement.umn.edu/.

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.

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.

Murphy, K. 2013. *Organic Quinoa Production in the Pacific Northwest.* Slides from webinar. http://eorganic.info/sites/eorganic.info/files/u461/eOrganic%20Quinoa%20Webinar%20Feb%2025%202013.pdf.

Murphy, K. 2017. Personal communication. April 10, 2017.

Murphy, K., J.C. Dawson, S.S. Jones. 2008. *Relationship Among Phenotypic Growth Traits, Yield and Weed Suppression in Spring Wheat Landraces and Modern Cultivars*. Field Crops Research 105: 107-115.

Norton, U.; Norton, J. B.; Garcia y Garcia, A.; Ritten, J. P.; DelGrosso, S. J.; Hergert, G. W. 2014. *Soil Carbon and Nitrogen Dynamics in Organic Crop and Forage Production of the Northern High Plains Ecoregion: Wyoming and Nebraska*. Proposal and final report for ORG project 2010-03952. CRIS Abstracts.*

Orf, J. H., T. E. Michaels, M. J. Sadowsky, and C. C. Sheaffer. 2016. *Improving Soybean and Dry Bean Varieties and Rhizobium Strains for Organic Systems.* Final report on OREI project 2011-01942. CRIS Abstracts.*

Philpott, T. 2010. *New Research: Synthetic Nitrogen Destroys Soil Carbon, Undermines Soil Health*. GRIST. http://grist.org/article/2010-02-23-new-research-synthetic-nitrogen-destroys-soil-carbon-undermines/.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., Seidel, R. 2005. *Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems*. *Bio Science* vol. 55 no. 7.

Place, G.T., S.C. Reberg-Horton, D.A. Dickey and T.E. Carter. 2011a. *Identifying Soybean Traits of Interest for Weed Competition*. Crop Science 51:2642-2654.

Place, G.T., S.C. Reberg-Horton, T.E. Carter, and A.N. Smith. 2011b. *Effects of Soybean Seed Size on Weed Competition*. Agronomy Journal 103:175-181.

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.*

Reinbott, T. 2015. *Identification of Factors Affecting Carbon Sequestration and Nitrous Oxide Emissions in Three Organic Cropping Systems*. Final report on ORG project 2011-04958. CRIS Abstracts.*

Rodale Institute. 2011. *The Farming Systems Trial: Celebrating 30 Years.* 13 pp. https://rodaleinstitute.org/our-work/farming-systems-trial/farming-systems-trial-30-year-report/.

Rom, C. 2013. *Best Management Practices for Organic Orchard Nutrition.* Final report for OREI project OREI 2008-01251. 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.

Sanchez, E. 2017. *Dealing with High Soluble Salts in High Tunnels.* Pennsylvania State University Extension Bulletin, 2 pp. http://extension.psu.edu/plants/vegetable-fruit/fact-sheets/salts-in-high-tunnels/dealing-with-high-soluble-salt-levels-in-high-tunnels.

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.

Shapiro, C. A.; Brandle, J. R.; Francis, C. A.; Knezevic, S. Z.; Lyon, D. J.; Schlegel, V. L.; Wright, R. J.; Wortmann, C. S.; Hergert, G. W.; Ferguson, R. B.; Quinn, J. E. 2014. *Improving Organic Farming Systems and Assessing their Environmental Impacts across Agroecoregions.* Final report for OREI project OREI 2009-01371. CRIS Abstracts.*

Shapiro, C. A.; Brandle, J. R.; Francis, C. A.; Knezevic, S. Z.; Lyon, D. J.; Wright, R. J.; Johnson, R. J. 2009. *Improving Organic Farming Systems Across Nebraska Agroecoregions*. 2009 progress report for OREI project 2005-04497.

Sheaffer, C. C., P. Nickel, D. L. Wyse, and D. L. Allan. 2007. *Integrated Weed and Soil Management Options for Organic Cropping Systems in Minnesota*. Final report for ORG project 2002-03806. CRIS Abstracts.*

Simon, P. W., J. Navazio, M. Colley, L. Hoagland, and P. Roberts. 2016. *Carrot improvement for organic agriculture with added grower and consumer value*. Final report on OREI project 2011-01962. CRIS Abstracts.*

Snapp, S. and S. Swinton. 2013. *Practical Perennials: Partnering with Farmers to Develop a New Type of Wheat Crop*. Final report for OREI project 2009-01332. CRIS Abstracts.*

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.

USDA NRCS, n.d. *Cover Crops - Keeping Soil in Place While Providing Other Benefits*. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ny/technical/?cid=nrcs144p2_027252

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

Worthington, M., S.C. Reberg-Horton, G. Brown-Guedira, D. Jordan, R. Weisz, and J. P. Murphy. 2015. *Morphological Traits Associated with Superior Weed Suppressive Ability of Winter Wheat against Italian Ryegrass*. Crop Science 55:50-56.

Yarwood, S. 2016. *Agricultural Greenhouse Warming Potential and Carbon Sequestration in Organic and Long-term Rotational Systems*. Proposal and progress report for ORG project 2012-02977. CRIS Abstracts.*

Zhou, X. 2016. *Sustainable and Profitable Strategies for Integrated Pest Management in Southern Organic Rice*. Project proposal and progress report for OREI project 2015-07384. CRIS Abstracts.*

* 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:

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