Reducing Organic Crop Production Risks through Soil Health Practices

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Organic Soil Health Education Webinar for Farmers and Ranchers in the Southern Region

January 13, 2021

SARE project LS20-324

Presentation Notes:

Slide 2 – *Farming is risky*

Even when weather favors good yields and pests, weeds, diseases, and soil nutrient levels are well-managed, high production costs or fickle markets can result in a loss for the current season. In addition, soil degradation can undermine production in future years, and subtle declines in soil health can take place without obvious warning signs such as the severe rill erosion in this photo. Thus, all farmers need to develop and implement a soil management strategy that builds and maintains healthy, living soils without adding excessively to production costs.

Slide 3 – *Leading production risks in the South*

The warm climates and long growing seasons of the Southern region intensify weed competition against crops and promote multiple generations and rapid spread of insect pests, plant pathogens, and parasitic nematodes.

While total annual rainfall is adequate to high through most of the region, periods of excessive rainfall are sometimes followed by prolonged dry spells. Wet soil conditions discourage deep, extensive root development and can promote root-rot diseases. When a hot, dry summer follows a wet spring, the topsoil dries out rapidly and the crop cannot cope because of its limited root system.

Slide 4 – *How organic farming mitigates risks*

In addition to the benefits listed on the slide, organic farms do not have to worry as much about weed resistance to conventional herbicides, as this trait does not make them “superweeds” that are also immune to crop competition, cultivation, mulching, and other organic weed control tactics. However, insect pests can evolve resistance to organic-allowable pesticides such as Bt or Spinosad.

Slide 5 – *Risks related to organic production*

Conventional farms can utilize fast-acting soluble fertilizers and synthetic crop protection chemicals to compensate for the impacts of sub-optimal soil health, adverse weather, or pests on production. Organic systems rely more on the biological functions of healthy soil for crop nutrition and crop protection – and these functions can be especially difficult to maintain in hot climates and highly weathered soils of the Southern region.

Many organic farmers cite the struggle to maintain soil health while keeping weeds from hurting crop yields – which requires tillage and cultivation – as one of their greatest challenges.

Organic fertilizers and amendments require biological processes to release their nutrient content in plant-available form, and the timing of nitrogen (N) release often does not ideally match crop N need. In addition, compost, manure, and poultry litter-based amendments often deliver more phosphorus (P) than crops need, which leads to a buildup of excess soil P, which can undermine soil health. Above-optimum soil test P can inhibit the activity of highly beneficial root-symbiotic arbuscular mycorrhizal fungi (AMF), which play critical roles in crop nutrition, drought resilience, and disease suppression. Heavy annual use of compost and other organic amendments can also lead to the buildup of other nutrient excesses, including calcium (Ca), zinc (Zn), and mineralizable organic N (leading to leaching losses similar to that from synthetic fertilizers).

In contrast, organic producers managing larger acreages or farming with limited financial resources often cannot afford to use organic fertilizers and amendments at rates sufficient to optimize crop yields and replenish nutrients removed in harvest.

Slide 6 – *Subtitle slide – climate change and risk*

Slide 7 – *Climate change exacerbates risks*

Climate change has increased the frequency of intense rainfalls (3 inches or more within a 24-hour period) in the Southern region (note the unprecedented number of landfalling tropical cyclones in 2020) and has also resulted in more erratic distribution of rainfall. The force of torrential rain hitting unprotected soil causes surface crusting and can compact the top several inches of the soil profile. This reduces the soil’s capacity to absorb and retain the heavy rainfall, and much of it may run off from sloping land and pond on level land.

Climate change has also led to more abrupt swings from periods of excessive rainfall to periods with little or no rain. When the former has reduced both plant root development and the soil’s capacity to absorb and retain moisture, the impacts of several weeks of hot, dry weather on crops are intensified in a phenomenon that has recently been dubbed “flash drought.” Severe crop losses and pasture degradation took place in parts of the southeast during the flash drought of 2019.

Another effect of climate change in the South has been a substantial increase in mean summer nighttime temperatures, which accelerates microbial respiration and associated oxidation (loss) of soil organic matter (SOM). Intense daytime heating of unprotected soil surfaces can further stress the soil life. Thus, climate change itself can compromise soil health, by accentuating the impacts of heat on soil life and fertility.

Warmer winters and earlier onset of spring has led to early bud break in fruit trees and other perennial horticultural crops, leaving them more vulnerable to untimely spring freezes that can cause a total crop loss for the current season.

Finally, climate shifts cause corresponding shifts in the life cycles and geographic ranges of many weeds, plant pathogens, and insect pests, resulting in greater pressure on crops. Longer frost-free seasons and higher mean temperatures allow some insect and nematode pests and plant pathogens to complete more generations per growing season, resulting in exploding pest populations. Some growers report new weeds, pests, or diseases that they have not seen in the past, and others have noted increased problems with existing harmful organisms.

Some of the region’s most aggressive cropland weeds, notably purple nutsedge and Palmer amaranth, reach their maximum photosynthetic capacity at 95-100°F, a temperature that slows growth of hot weather crops like corn, cotton and soybean, and disrupts pollination in tomato, pepper, and other fruiting vegetables. Thus, hotter weather can give weeds a competitive edge on crops.

Slide 8 – *Climate change, soil health, and crop production*

Climate change has made the task of building healthy living soils both more difficult and more urgently vital to the future of all farming – organic and otherwise.

Healthy soils improve crop resilience to drought and other adverse weather conditions and help to mitigate climate change by sequestering carbon and reducing emissions of the powerful greenhouse gas nitrous oxide (N2O). At the same time, climate change itself speeds the loss of SOM and may alter soil microbial functions, thereby reducing the soil’s capacity to protect crops from the direct impacts of weather extremes.

Slide 9 – *Subtitle slide – How healthy soils reduce risk*

Slide 10 – *How healthy soils reduce risk: soil life*

Beneficial soil organisms enhance crop resilience by facilitating nutrient and moisture uptake and protecting plants from pathogens. While pathogens and root-feeding nematodes can be found in healthy soil, they are greatly outnumbered by beneficial organisms that perform these vital functions for crop health and can also exclude pathogens from plant root surfaces and help stabilize soil organic matter (sequester carbon).

Slide 11 – *Plant-soil-microbe partnerships*

Many crops, including legumes, cereal grains, tree and small fruits, and vegetables in the allium (onion), solanaceous (tomato), and cucurbit families form strong associations with arbuscular mycorrhizal fungi (AMF). These fungi grow both within root tissue and out into the soil, thereby greatly expanding the “reach” and efficacy of the root system, unlocking N, P, and micronutrients from soil minerals and organic matter, enhancing moisture uptake, and deterring soilborne pathogens. Thus, AMF comprise a key risk reduction ally in organic production.

Nitrogen fixation through the legume-*Rhizobium* symbiosis is perhaps the most widely known and utilized plant-microbe partnership. In addition, corn, pearl millet, and some other grains can meet some of their N requirement through N fixation by *Azotobacter, Azaspirillum*, and other “free living” soil N fixing microbes proliferating in their root zones.

In addition to suppressing root pathogens through direct competition for rhizosphere space or by direct antagonism, antibiosis, or predation, some beneficial soil microbes protect plants from *foliar* diseases through a plant immunity response called Induced Systemic Resistance (ISR). *Trichoderma harzianum* fungi in the root zone of tomato show potential to protect the crop from late blight (*Phytophthora infestans*) and gray mold (*Botrytis cinerea*) through ISR. Several soil organisms, including some strains of *Pseudomonas* bacteria, have been identified as carrot root endophytes (growing within the root tissue) that enhance carrot growth and protect the crop against a major foliar disease, *Alterneria dauci* leaf blight.

In order to realize the full potential for beneficial plant-soil-microbe partnerships, the desired organisms must be present and active. Healthy soil provides sufficient “food” – active SOM, and the living roots and residues of a diversity of plants – to sustain the desired microbial community. In addition, low to moderate levels of plant available N and P in the bulk soil promote plant partnership with mycorrhizal fungi and N fixing microbes, while very high nutrient levels render these organisms dormant, making crops less resilient and more dependent on fertility inputs.

Different crop cultivars and breeding lines show contrasting capacities for beneficial microbial interactions, which indicates that plant breeding can play an important role in soil health, crop resilience, and risk reduction in organic production.

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Slide 12 – *How healthy soil reduces risks: nutrients*

The community of soil life plays multiple vital roles in retaining and delivering nutrients to crops. Decomposer bacteria, fungi, and other soil organisms process manure, crop residue, and other organic materials into active and stable soil organic matter (SOM) that act as storehouses for essential crop nutrients. Active SOM includes nitrogen (N), phosphorus (P), and sulfur (S) that soil microbes gradually release as they utilize the active SOM as their food source.

Stable SOM greatly enhances the soil’s cation exchange capacity (CEC), which consists of negatively charged surface area that holds positively charged potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and several micronutrients in plant-available form.

Some soil microbes facilitate the mobilization of K and other nutrients from soil minerals into plant-available forms.

Many microbes proliferate in the crop root zone, where they release nutrients from residues, active SOM, or smaller organisms on which they feed, directly to plant roots for efficient uptake. When this process works optimally (tightly coupled nutrient cycling), crops obtain sufficient N, P, and other nutrients even when bulk soil soluble N and P levels are quite low. Tight nutrient cycling can protect water quality, curb N2O emissions, and reduce fertilizer input costs.

Surplus levels of plant-available N and P can compromise soil health by altering the soil microbial community. High levels of P are known to inhibit the plant root symbiotic mycorrhizal fungi that play multiple essential roles in the resilience and vigor of many crops. High soluble N levels suppress the activity of nitrogen fixing bacteria and reduce the soil life’s capacity to mineralize N from SOM for crop uptake. Thus, when nutrient inputs – from organic or conventional sources – exceed crop need and result in elevated soil NPK levels, soil health and nutrient efficiency can suffer.

Slide 13 – *How healthy soil reduces risks: physical properties*

The loose, crumbly structure of healthy soil makes it both easier to work (requiring less intensive tillage to prepare seedbeds, plant crops, and manage weeds) and more resilient to the negative effects of tillage as well as torrential rains and other weather extremes. Soil coverage (crops, residues), plant roots, beneficial soil organisms, and both active and stable organic matter all contribute to good physical soil condition, and thereby reduces costs of production as well as risks of soil loss, planting delays, and crop establishment failures.

Reduced need for tillage in turn reduces future stresses on the soil and helps maintain soil health.

Slide 14 – *How healthy soil reduces risk: water relations*

In addition to increased topsoil water holding capacity, healthy soil with a deep, open profile further enhances plant-available water by allowing full development of crop root systems that can access subsurface moisture reserves.

In irrigated systems, improving soil health reduces both frequency of irrigation and total amount of water needed to produce the crop, thereby reducing irrigation costs, which can be substantial in water limited regions such western Texas and Oklahoma.

Slide 15 – *Soil resilience in deluge and drought*

These examples are from outside the Southern region, but the same principles apply here.

Slide16 – *Soil health, drought, flood, and risk*

Southern region organic producers must often work with depleted soils, especially when transitioning a field from conventional to organic production. Skillful use of compost, organic fertilizers, and other natural amendments, combined with favorable weather, can sustain good yields. However, the high production costs of input-intensive organic production can approach or exceed gross proceeds, resulting in significant financial risk to the farm. In addition, soils in compromised health show much less resilience to the impacts of drought or excessive rainfall, as illustrated in this hypothetical example of production records over the next six years.

As soil condition improves, transitioning to a soil health management strategy with lower inputs and greater emphasis on grown-in-place fertility (cover crops, intercrops, etc) can reduce costs and improve net returns. While the high input system may slightly out-yield the soil health system in favorable weather years, healthy soil conditions will minimize losses to drought and flood, and lower input costs enhance net returns and reduce financial risk.

Slide 17 – *Subtitle slide – Building healthy soil to reduce risk*

Slide 18 – *The journey to soil health: NRCS Four Principles of Soil Health*

About 10 years ago, the USDA Natural Resources Conservation Service (NRCS) established a set of four principles of soil health management. These principles have been widely validated through research and farmer experience over the past 50 years.

Keeping the soil surface covered by living vegetation and/or plant residues is essential for preventing erosion and protecting soil life and soil structure near the surface. Diversifying the cropping system supports a more diverse community of soil life that can better perform the full of vital functions of a healthy soil.

Living plant roots provide the “daily bread” for the soil life. Plant root exudates and fine root sloughing feed beneficial organisms, whose activities maintain soil structure, drainage, and aeration; retain moisture and nutrients for crop use; and protect crops by suppressing disease and inducing systemic plant resistance to pathogens and other stresses. *Without living plants, soil cannot remain healthy*.

When NRCS first issued the Four Principles, “minimizing disturbance” focused mainly on avoiding or minimizing tillage, thereby protecting fungal networks and larger soil organisms (earthworms, springtails, mites). This principle has since been expanded to include minimizing chemical stresses from agricultural inputs (pesticides, herbicides, fungicides, and concentrated fertilizers); as well as biological disturbances including overgrazing and invasive exotic plant species. Some invasive exotic plants take over and crowd-out native vegetation and crops in part by disrupting the indigenous soil microbiome.

While conventional fertilizers and crop protection chemicals are generally more disruptive than “organic” inputs permitted by the USDA Organic Standards, significant disturbance can also result from concentrated organic nutrient sources like poultry litter, and some organic biocides such as vinegar herbicide or copper fungicide.

Slide 19 – *The living plant is the #1 tool for building healthy soils*

The first three NRCS soil health principles place living plants at the center of soil health management. NRCS working lands conservation programs support farmers to utilize enhanced “vegetative practices” from cover crops to conservation buffer plantings, and the National Organic Standards require diverse crop rotations that include cover crops, sod crops, and green manure crops.

Healthy, living soils develop through an ongoing partnership between plant roots and beneficial soil micro and macro-organisms. Photosynthesis creates the raw materials for plant growth, crop yield, and soil life. Plant cover protects the soil surface from overheating and drying by direct sun, and the erosive effects of intense rainfall and winds. Living roots work with the soil life to build and maintain SOM, soil structure, pore space, and moisture- and nutrient-holding capacity. All of these processes contribute to soil and cropping system resilience to extreme and erratic weather related to climate changes. In addition, this plant-soil-microbe partnership can effect a net conversion of atmospheric carbon dioxide into stable SOM (carbon sequestration) – which means that good soil health management not only builds resilience to weather extremes but also contributes to climate stabilization.

Slide 20 – *Bare soil is at risk*

Many crop rotations not only lack diversity but also include prolonged periods of unplanted fallow. For example, a cotton-peanut rotation with no winter cover crop may leave the soil idle and unprotected for six months a year. Adding sorghum, rice, and sunflower enhances diversity (five crops from four plant families), but with nothing growing during a mild Southern winter, these rotations still miss a major opportunity for the soil to feed itself while it is not in production for income. In addition, while each of these five crops can benefit from arbuscular-mycorrhizal fungal (AMF) associations, populations of these valuable fungi lack a “green bridge” after each crop is harvested, so that their populations decline by the time the following crop is sown.

Many field crop farmers use no-till to save soil, leaving post-harvest crop residues on the surface as shown here. However, this does not feed soil life as effectively as living plant cover, and nutrient leaching losses, crusting, compaction still occur, especially during a rainy winter.

In organic systems that do not use herbicides, weeds will emerge to help protect, feed, and restore soil … and increase weed control costs and soil-disturbing cultivation for the next crop.

Slide 21 – *Cover crops save soil in Floyd, VA*

Potato digging leaves the soil bare, fluffed-up, and especially prone to erosion. At this homestead, wise gardeners sowed sorghum-sudangrass the day after the potatoes were harvested in late July, thereby preventing catastrophic erosion. This vigorous cover crop, which can attain high biomass within six to eight weeks almost anywhere in the Southern region, also forms a deep, robust, fibrous root system that can hold soil against raging floodwaters.

In 2015, autumn rains set records in Floyd County: over 20 inches in five weeks, seven of them on the day that this flood occurred. As climate change makes such extreme rain events more common, timely cover cropping can save soil by the ton.

Slide 22 – *The journey to soil health: investments and risks*

While healthy soil reduces a range of production risks, the process and practices entailed in restoring and maintaining soil health can entail some new risks and costs for the operation. For example, cover crop seed might cost $20 – 100 per acre and require additional field operations and possibly new equipment for planting and termination.

New practices often require new knowledge and skills. For example, in low-rainfall regions, cover crops need to be selected, timed, and managed so that they do not consume soil moisture needed by the following crop.

Some practices, such as no-till cover crop termination and cash crop planting, can reduce yield in modern cover crop varieties even as soil health benefits accrue. Other practices, such as rotating an intensively managed vegetable field into a sod crop, can be especially effective in restoring tilth, SOM, and fertility, and reducing annual weeds, yet entail foregone income.

Soil health practices represent a long-term investment, and these short-term costs can pose barriers to effective adoption. The goal of this webinar is to provide practical guidance for overcoming some of these barriers to adopt effective soil health management in organic systems.

Slide 23 – *Step1: Assess your resources*

An excellent tool for identifying the inherent properties of your soil is the NRCS Web Soil Survey, available at <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>. Use this tool to identify your soil types and their inherent capabilities and limitations.

Slide 24 – *Step 2: Review your practices*

Reviewing your current crop rotation and other practices can help identify the “low hanging fruit” – changes that can have a significant impact and are relatively easy to adopt with current knowledge and resources. Examples might include sowing a winter or summer cover crop in a currently fallow period, replacing a cultivation pass with a non-soil disturbing weed control tactic such as flame or mowing, or dropping an expensive amendment that may not be paying for itself in crop yield or soil improvement.

Slide 25 – *Step 3: Build a resilient production system for your site*

Adding new crops to your production system addresses the first three NRCS principles of soil health: keep the soil covered, maintain living root, and increase diversity. Reducing tillage helps to minimize physical disturbance to the soil system, while adjusting inputs to meet but not exceed production needs helps to avoid chemical disturbances to the soil life related to high levels of soluble nutrients as well as nutrient deficiencies and imbalances among nutrients.

Build your system one step at a time, trialing new practices and assessing their economic viability before implementing them on the whole farm.

Slide 26 – *Subtitle slide – Adding crops*

Adding new crops to an existing cropping system benefits soil health in several ways:

* Increasing duration (% of rotation timeline) of soil coverage by plants and their residues.
* Increasing duration of living roots to keep the soil life nourished.
* Increasing total plant biomass (roots, exudates, aboveground residues) added per year.
* Increasing soil microbiome functional diversity through increased plant species diversity.

Slide 27 – *Adding cover crops*

The many benefits of cover crops are well known, yet far fewer than half of US farmers have adopted the practice because of the challenges and potential risks of adding them to the rotation. Anytime the soil is not occupied by production crops or other vegetation is a missed opportunity to build and maintain soil life and soil health. Yet the cover crop itself entails a significant investment in seed, planting, and termination, with no *direct* financial return. Other cover crop risks include the potential for delayed planting of the following production crop, complications with crop establishment in presence of cover crop residues, or consumption of soil moisture in rainfall-limited situations. Finally, adverse weather and soil conditions after seeding, late planting (too close to onset of winter or to extreme summer heat), or poor quality seed can lead to a cover crop failure.

Slide 28 – *SARE cover crop surveys*

SARE conducted surveys of 1000+ farmers after the 2012, 2013, 2014, 2015, 2016, and 2019 growing seasons to estimate yield and other benefits from cover cropping, and to document the primary reasons that farmers plant cover crops. The percentages of farmers citing benefits listed in the slide are from the 2016 survey.

Outcomes of cover cropping on a single farm or in a single study can vary widely and result in misleading conclusions about the value of this practice. SARE conducted these surveys to get a better handle on whether cover cropping actually pays over the long run in terms of farm economic viability as well as soil health, climate resilience, and carbon sequestration.

While yield increases have been generally modest (2 – 5%), cover crops have also reduced fertilizer and weed control costs, resulting in a net increase in economic returns for 33% (field crop growers, 2016) to 58% (horticultural crop growers, 2019) of respondents. Very few respondents reported net economic losses.

The 2019 survey included 230 horticultural crop producers (mainly vegetables and fruit), who used cover crops to improve soil health (94%), help manage weeds (81%), reduce erosion (71%), and increase water infiltration (63%).

SARE also issued a bulletin exploring how to make cover crops pay in field crop production, based on the 2012-16 surveys.

Most of the farmers in the SARE cover crop survey are not using organic methods. Organic farmers who depend more heavily on cover crops for N fixation, nutrient cycling, pest mitigation, and soil fertility may realize an even larger net economic benefit from this practice.

References:

* *National Cover Crop Surveys* offer farmers’ viewpoints on long term soil health, production, and financial benefits of cover cropping. Most recent report 2019-20. <https://www.sare.org/publications/cover-crops/national-cover-crop-surveys/>.
* *Cover Crop Economics: Opportunities to Improve your Bottom Line in Row Crops*. 2019 bullletin, 24 pp. Based on Cover Crop Surveys in 2012-2017.

Slide 29 – *Adding cash crops: diverse rotation*

This hypothetical three-year rotation includes a cool season crop followed by warm season crop for each of three successive years While it only includes a single cover crop (rye), it also represents six different plant families (grass, legume, crucifer, cucurbit, composite, and solanaceous) that offer a diversity of rooting depths and architectures, support different and complementary microbiomes, slow the development of many plant pathogens, and keep weed populations in check with varied planting and harvest dates, above-ground growth habits, and competitive abilities.

Crop diversification can enhance soil organic matter, biological activity, and nutrient and water use efficiency, even if total plant biomass or annual coverage is not increased. This is because the greater diversity of plant species supports a greater diversity of soil and rhizosphere (root zone) microbes, yielding a more functionally diverse community of soil life that can improve nutrient cycling, plant disease suppression, soil structure and moisture retention, and other key functions.

Diversifying production crops presents both new opportunities and new challenges related to markets. On the one hand, adding a new crop may entail acquiring new skills and equipment, and managing a more complex system. On the other, enterprise diversification contributes to the economic stability of the operation, as failure of one crop is less likely to lead to a devastating net loss for the year.

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Slide 30 – *Adding a sod phase to the rotation*

Adding a perennial sod phase of two to five years to an existing intensive annual crop rotation can go far toward restoring soil health and fertility, relieving compaction and improving structure, and reducing weed seed and pest populations. However, those years out of crop production can entail a lot of foregone income in a crops-only farming system, and may be feasible only if the farmer has sufficient land to meet market needs on 50 or 60% of their total arable land. Farmers that raise both crops and livestock can integrate the latter by grazing or haying the sod phase of the rotation. Rotational grazing can further enhance soil health benefits of the sod phase through increased root sloughing and regrowth during the grazing-and-rest cycles, as well as well-distributed manure deposits.

Slide 31 – *Do cover crops “steal” soil moisture and nutrients?*

Many farmers hesitate to grow cover crops because they consume moisture and nutrients without offering a direct financial return. In the short term, this is true, but in the long run, cover crops enhance both plant available moisture and nutrient availability through their beneficial effects on soil health.

Slide 32 – *Soil condition and moisture capacity*

Soil texture and condition govern how well the soil will absorb and hold rainfall within the plant root zone to support crop growth. A deep, open soil profile with low bulk density, good aggregation, and ample small to large pore space will retain most or all of the rain it receives yet maintain sufficient aeration for root health. A surface crust or subsurface compaction hinders absorption of rainfall, resulting in runoff during heavy showers and reducing the amount of moisture the soil can store. A subsurface hardpan can also block penetration by plant roots, so that crops cannot access deep moisture.

A sandy soil that is low in organic matter has mostly large pores that allow the water to soak in rapidly, so that little or no runoff occurs. However, the soil profile cannot retain much moisture, so some of the rainfall drains beyond the reach of plant roots and is thus not available for crop production.

Cover crops play a vital role in maintaining a healthy, open soil profile, and can gradually improve the moisture holding capacity of compacted or depleted, sandy soils. Deep-rooted crops also recover soluble N throughout the sol profile and thereby minimize N losses to leaching.

Conversely, if the healthy soil in the left-hand panel is left fallow for long periods of time between successive production crops, any N mineralized by the soil life may be leached by the next heavy rain. In the longer run, the soil’s SOM level and capacity to hold plant-available water will decline.

Slide 33 – *The challenge of coastal plain soils*

One of the reasons many sandy soils in the Southern region are so drought-prone is that crops remain shallow-rooted because they cannot penetrate a subsurface compaction layer, often consisting of a highly leached, “E” horizon below the topsoil or A horizon. When the topsoil dries out, crops cannot access the substantial moisture and nutrient reserves in the clay-enriched “B” horizon., and thus undergo drought stress and sometimes nutrient limitations.

Slide 34 – *Winter rye improves cotton yield in South Carolina coastal plain*

Unlike cotton and other warm season row crops, winter rye and radish roots can penetrate the compacted E horizon, partly because autumn rains and lower evaporative demand result in higher soil moisture content in the fall, making the E horizon less restrictive to root growth. After the rye is terminated in spring, its decaying roots leave channels through which cotton roots can penetrate to reach subsoil moisture and nutrient reserves. While tillage radish was killed prematurely by unusually severe freezes in this study, the fibrous root system of the rye was sufficient to accomplish biological suboiling, thus making deep mechanical tillage unnecessary.

In addition, adding the winter cover crop to the rotation significantly enhanced SOM and moisture holding capacity throughout the profile.

In another study conducted in a very different soil type (silt loam, no E horizon) near Clemson, SC, winter cereal-legume cover crop mixtures generated 2 to 3 tons dry weight biomass per acre but did not deplete soil profile moisture at all compared to either weedy or weed-free (bare) fallow.

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Slide 35 – *Water consumption by cover crops can be beneficial*

Farmers can optimize cover crop use of soil moisture by adjusting date of termination: later in wet conditions to maximize consumption of excess moisture, and earlier in dry conditions to conserve moisture. The growing cover crop itself also contributes to the soil’s porosity and capacity to absorb rainfall without ponding or runoff.

Slide 36 – *Summer cover crops conserve soil N*

Multiple studies have demonstrated the capacity of winter cover crops to reduce N leaching losses by taking up leftover soluble N. While this results in a short-term tie-up of plant available N and may necessitate higher N application rates to crops grown immediately after mature cover crops, the cover cropping practice enhances the soil’s capacity to mineralize (release) N to meet the needs of subsequent cash crops. Grass cover crops (high C:N ratio) are most efficient at taking up soluble N, while legume cover crops (low C:N ratio) mineralize the most N for the following crop.

In this study, conducted at the NCSU Center for Environmental Farming Systems (CEFS) in Goldsboro, NC, on a Wichkam sandy loam (deep, well-drained coastal plain Ultisol with a moderately clay-enriched B horizon), summer cover crops were sown in May, grown until August, flail-mowed, and tilled in a week later. The goal of the study was to determine whether summer cover crops would confer similar N cycling benefits. A hot summer with moderate drought was followed by a record-breaking rain in September, a month or so after cover crops were terminated.

Four different cover crops with varying C:N ratios from 57 for sorghum-sudangrass, 15 for southern pea, and intermediate values for foxtail millet and a millet-pea mixture, all utilized N from the soil, resulting in lower soluble N levels in August and September compared to a no-cover control treatment. Yet, in laboratory incubation studies, residues of all four cover crops enhanced soil microbial biomass, microbial activity, and potential to mineralize N compared to the unplanted fallow soil. As expected, the high C:N grasses had the greatest capacity to ”mop up” soluble N while growing, while the southern pea showed the greatest and most rapid N mineralization.

The practical significance of this study is that in this time of increasingly erratic extremes of drought, hurricane, and other heavy rain events, summer cover crops can conserve soil N and minimize leaching losses, yet make the N available to future crops.

Reference

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Slide 37 – *Winter cover crops recycle N during mild, rainy winter*

An organic systems trial was conducted in the Salinas Valley of California, which has a Mediterranean climate with mild, rainy winters and warm dry summers suited to irrigated vegetable production. The soil is a Chualar loamy sand, which is well drained but has a compacted subsurface horizon, whose high bulk density restricts root growth at and below 30-inch depth.

A crop rotation of spring lettuce followed by fall broccoli fertilized with 145 lb N/ac was maintained over an eight-year period. Broccoli harvest removed only about 25% of this applied N. Whenever the soil was left fallow over winter, much of this N leached and lettuce yields the following spring, were N-limited, ranging from 15,000 lb/ac to complete crop failure.

Growing a high-biomass cover crop during the winter rainy season greatly enhanced lettuce yields, to an average of 30,000 lb/ac. Similar results were observed after rye (high C:N), mustard (low C:N) and a rye-legume mix (moderate C:N). This is a striking result, especially considering that the N-immobilizing effects of rye and its residues are generally expected to increase the need for N to sustain yield in the following crop. It also shows that the main effect in this trial is recovery of the 100+ lb/ac N leftover from organic broccoli production, rather than N fixation, which would have taken place only in the legume-rye mixture.

In this trial cover crops were used in conjunction with compost applications and other organic practices that built and maintained healthy, biologically active soils. The cover crops enhanced soil microbial activity and biodiversity, and worked in conjunction with the compost to build active and stable SOM.

References:

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Slide 38 – *Cover cropping in low-rainfall regions*

In semi-arid regions such as the western two-thirds of Texas and Oklahoma, cash crops and cover crops in the rotation may compete 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 yields of the following production crop are reduced. 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 in organic systems is often complicated by perennial weeds.

Yet, not growing a cover crop can further reduce SOM and fertility, aggravate erosion, and reduce long term soil water holding capacity. Prolonged fallow (e.g. a two year wheat/fallow rotation) degrades soil quality even under continuous no-till.

Thus, cover cropping remains essential, and care is needed in selecting the cover crop, planting and termination dates to ensure sufficient available moisture for the following crop. In several trials in the Northern Great Plains, winter-planted field peas have offered significant benefits (N, weed suppression, long term soil health) with minimal depletion of soil moisture; and this cover crop merits additional research for suitability to the Southern High Plains.

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Slides 39 and 40 – *Drought resilience and water use in cover crops*

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 light moisture use, while field pea and medic have shallow roots and low water requirements. In contrast, the drought resilience of alfalfa, sunflower, safflower, rye, and triticale is based largely on their capacity to tap – and often deplete – moisture reserves throughout the entire soil profile. For example, alfalfa typically extends roots to 6 to 10 feet, and sometimes as deep as 30 to 40 feet. Montana State U researchers report that crops grown for the first year or two after alfalfa sod is broken can suffer increased moisture deficits and lower yields compared to crops grown after less moisture-demanding covers or fallow.

Thus, growers in rainfall-limited regions should select cover crops that have both high drought tolerance and low water use intensity. A similar strategy may be appropriate for drought years anywhere in the South.

References:

* Managing Cover Crops Profitably, by Andy Clark,. 3rd ed. (SARE Handbook 9).
* PLANTS Database <https://plants.sc.egov.usda.gov/java/>. Enter the cover crop in “name search” and download the Plant Guide (pdf or doc) under General Information.
* USDA Cover Crop Chart 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.

<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>.

Slide 41 – *Plan for both dry and wet extremes*

Unfavorably dry or wet soil conditions at time of cover crop planting is a common cause of poor cover crop stands. As climate change makes rainfall ever more erratic and unpredictable, these risks increase – and can be mitigated through careful choice of cover crops. Have on hand seeds that will tolerate either extreme and select the ones best suited for actual conditions at planting time – or mix cover crops for dry and wet conditions to cover all contingencies.

Note that Japanese millet, sorghum-sudangrass, and rye show significant tolerance to both wet and dry conditions.

In regions with high mean annual rainfall (40 inches or more) with erratic distribution, there is less risk than in semiarid regions (~15-20 inches per year) in the use of high moisture-use, drought resilient species such as rye, Japanese millet, and sorghum-sudangrass. In fact, their moisture consumption can become beneficial during a wet spell, reducing delays in getting into the field for cash crop planting.

Slide 42 – *Subtitle slide – reducing tillage*

Slide 43 – *No-till planting in roll-crimped cover crop*

Continuous no-till is generally not feasible in organic annual crop rotations. Organic no-till, also known as rotational no-till, consists of terminating a mature (flowering ), high-biomass, weed-free cover crop without tillage or herbicides, using a roller-crimper, flail mower, or seasonal timing that will guarantee a complete winter-kill of the cover crop. No-till equipment is then used to transplant vegetable starts, sow large-seeded crops (beans, corn, cucurbits), or plant seed potatoes, onion sets, or garlic. Small-seeded crops often fail if direct sown through cover crop residues. After cash crop harvest, fields usually need some tillage to plant the next cover crop.

In multiple long-term farming systems studies in the Southern region and elsewhere, organic rotational no-till systems have accrued more active and stable SOM, microbial activity, and functional soil biodiversity than either continuous no-till with conventional inputs, or organic with full tillage prior to each cover and cash crop (which in turn sustained better soil health than tilled conventional systems). However, crop yields in the organic no-till have varied from satisfactory (similar to tilled systems) to near total crop failures. In colder climates (upper Midwest and Northeast), delayed cash crop planting, cold wet soils, and inadequate N mineralization often hurt organic no-till yields, while in the South, the major yield limiting factor is intense weed pressure.

In short, while organic no-till offers great soil health benefits, it also poses substantial costs and risks. Try it first on a small scale, and plan for a substantial learning curve as you adapt the system to your local, soils, climate, and cropping system.

Slide 44 – *Organic no-till requirements*

Most annual cover crops can be killed mechanically without tillage or herbicides when the cover crop is in full to late bloom, or early seed development. Cereal grains are best terminated anytime between pollen shed and the “milk” stage of grain development, before seeds become viable.

If you can see the soil surface or identify weeds when you look down on the mature cover crop from above, or there are distinct gaps in the stand, the cover crop is not adequate for organic no-till. A four ton per acre (above ground dry weight) cover crop is generally at least three to four feet tall and completely covers the ground with a dense canopy.

In fields with moderate populations of annual weed seeds, a high-biomass roll-crimped cover crop will suppress weeds during the cash crop establishment period (4 – 8 weeks). Flail-mowed or frost-killed residues may be less effective. Creeping perennial weeds like Bermuda grass, Johnson grass, nutsedge, or Canada thistle will readily grow through a rolled cover crop.

A leguminous cash crop with good N-fixing potential can be planted into a roll-crimped cereal grain such as rye. The cover crop will temporarily tie up soluble N, thereby retarding weed growth without adversely affecting the legume. Conversely, a heavy N feeder like corn will thrive in a legume cover crop residue, and some farmers in Kentucky and Tennessee have had good results with organic no-till corn after vetch, peas, and/or crimson clover.

Slide 45 – *Practical options for reducing tillage intensity in organic systems*

Rick Felker of Mattawoman Creek Farms on the Eastern Shore of Virginia has enhanced the health of his sandy soils by gearing-down the rototiller PTO speed and increasing tractor forward speed to 2.5 mph. The usual practice of running a rototiller at maximum PTO speed with a forward speed of ~1 mph leaves the soil pulverized and prone to crusting and erosion. Gearing-down the tiller and moving faster has protected soil aggregation and minimized crusting after seedbed preparation.

Spading machines (rotary and reciprocating spaders) accomplishe deep non-inversion tillage without compaction and with less damage to soil health than other primary tillage implements. The spader is highly versatile and many vegetable producers report that it can incorporate a high biomass cover crop or even sod and create a seedbed suitable for transplanting or large-seeded crops in a single pass – while doing minimal damage to soil life or soil aggregates. It does require a slow tractor speed, and thus may be most practical for small to moderate size horticultural crop production.

Compared to “conventional” tillage of plow, disk, and rototiller, the spader substantially reduces compaction between 5 and 12 inches below the soil surface, and sometimes improves crop yields.

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Slide 46 – *Strip tillage*

Strip tillers part cover crop residues and work up a narrow (4 – 12 inch) swath of soil to take out weeds, speed soil warming, promote N mineralization, and facilitate seed-soil contact in planting rows. Conventional planting equipment can then be used to sow or transplant crops, while the majority of the soil surface area remains undisturbed and protected by residues.

Ridge tillage is another approach to limiting soil disturbance to crop rows. Ridge tops are cleared of cover crop residue in the spring to plant row crops and are rebuilt during interrow cultivation after row crop emergence.

References

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* *Conservation Tillage Systems in the Southeast: Production, Profitability, and Stewardship*. SARE Handbook 15. Jason Bergtold and Marty Sailus, editors, 2020. <https://www.sare.org/resources/conservation-tillage-systems-in-the-southeast/>.
* Photos in slide are from presentation by Cogger et al., 2012*, Soil Quality in Intensive Organic Management Systems* (Washington State University); and from a field day at North Carolina Agriculture and Technology State University in Greensboro, NC.

Slide 47 – *Shallow tillage*

Often, a shallow tillage can meet weed control or soil preparation needs while leaving the deeper parts of the soil profile intact, thereby avoiding subsurface compaction and reducing harm to earthworms and other soil life. Several conventional tools (light disk, field cultivator, springtooth harrow, rototiller) can be adjusted to till shallowly (1 to 4 inches). The challenge is to avoid pulverizing surface aggregates, which can lead to crusting or erosion.

Newer tools such as the power harrow shown here have been designed specifically to till the soil shallowly and conserve aggregates.

Meta-analyses of multiple studies indicate that shallow tillage and deep non-inversion tillage (chisel plow) has less negative impacts on soil life and soil health than deep inversion tillage (moldboard plow), and that shallow tillage in conjunction with organic practices can enhance SOM. Compared to the moldboard plow, shallow tillage or ridge tillage enhances subsequent crop root colonization by arbuscular mycorrhizal fungi nearly as much as no-till and was especially effective in combination with cover cropping. The greatest benefits from all these practices were observed on sandy soils.

In a long term (21 yr) trial in Germany, “minimum tillage” (3 inches) and organic practices together improved SOM and microbial biomass more than either practice alone.

References

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Slide 48 – *Sweep plow undercutter*

The blade plow, or sweep plow undercutter, is a valuable tillage tool for organic crop production, and was found to terminate most cover crops effectively in North Carolina trials. It is a popular tool for cover crop and weed management in lower-rainfall regions, and is less effective in wet soils.

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%. The blade plow also reduces wind erosion compared to disking for weed and residue management. Research is needed to confirm that this tool would confer similar benefits in the Southern High Plains.

References:

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Slide 49 – *Subtitle slide – adjusting inputs*

Slide 50 – *Nitrogen risks in organic production*

Nitrogen is the trickiest nutrient to manage organically. While conventional farmers can use soluble N fertilizers in precision dosage and timing, organic systems rely on biological processes to release plant-available N from cover crop residues, soil organic matter, and organic fertilizers. The amount and timing of N mineralized from these sources depends on season and weather conditions; soil type and texture; soil moisture and existing nutrient levels; the C:N ratio of amendments and cover crop residues added; and soil biological activity, biotic community structure, and other aspects of soil health. Thus, N release can be difficult to predict, and organic crops often suffer N deficiency and lower yield.

The risk of inadequate N is greatest on soils in below-optimum health such as fields newly transitioning from conventional to organic practices; after incorporating organic materials with a high C:N ratio such as straw, wood chips, or a mature grass cover crop; or in circumstances when the peak of N mineralization occurs well before or after the peak of crop N demand. In the latter case, an organic field can show both N leaching and crop N deficiency.

Efforts to overcome N limitation by increasing the use of concentrated organic N fertilizers such as poultry litter, feather meal, or blood meal increases costs of production and can accelerate the loss of soil organic matter, shift the soil microbiome away from the most beneficial types (mycorrhizal fungi, N fixing and N-cycling bacteria), and reduce the soil’s capacity to retain N against leaching and to release N from SOM and in a timely manner to meet crop needs. This make future crop production more dependent on N inputs. High soluble N levels can also threaten groundwater quality and stimulate weed growth.

Conversely, N mineralization from healthy, biologically active soils can greatly reduce or even eliminate the need to apply N. For example, in two years of field trials at Clemson University on a Piedmont sandy loam, tomato and summer squash yielded well after a winter cover crop of rye + crimson clover (~8,000 lb/ac biomass, 130lb/ac N) was either roll-crimped or mowed and tilled in. Vegetable crops showed no significant response to adding 50 or 100 lb/ac N in organic fertilizers, indicating that the soil microbiome already met crop N needs through mineralization from SOM and cover crop residues. The experimental field was under long term organic management and had 4.6% total SOM, an excellent level for this soil type.

Not all organically managed soils will perform this well in feeding the crop, and a strictly “feed the soil” strategy can lead to crop failure in different circumstances, particularly in soils without a long history of organic or sustainable management. The challenge is to discern how much N and other nutrients are actually needed.

Reference:

* Robb, D. 2015. *Weeds, Nitrogen, and Yield: Measuring the Effectiveness of an Organic No-Till System*. Final report, Southern SARE project 13-126.

Slide 51 – *Compost and manure can feed the weeds*

Comparative responses of crops (field corn, kale) and weeds (lambsquarters, Powell amaranth, common ragweed, foxtails) to composted poultry litter (5-4-3 N-P2O5-K2O analysis) shown in the diagram were documented in organic vegetable and field cropping systems trials at Cornell University. In these trials, high poultry litter compost rates stimulated more weed growth than equivalent amounts of N (feather meal) or K (potassium sulfate), which suggests that weeds were responding to all three major nutrients in the high analysis compost.

Tilling-in an all-legume cover crop can stimulate a flush N responder weeds. Strong N fixers like soybean can gain an edge over N-responsive weeds when plant available soil N is low (for example, after a winter cereal grain cover crop or a high C:N soil amendment).

Many crops form strong, beneficial arbuscular mycorrhizal fungal (AMF) associations, while many agricultural weeds – including pigweeds, lambsquarters, smartweeds, wild mustard, and nutsedges – do not. The P excesses that can accrue with regular use of manure and compost may deter AMF activity, thereby eliminating this crop advantage over weeds.

Uncomposted or cool-composted (<130°F) manure can pose food safety risks. The NOP-required 120-day interval between manure application and food crop harvest is a good guideline for all farms to minimize this risk.

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Slide 52 – *Nutrient strategies and risks*

Organic producers face risks of both insufficient NPK applications (especially in depleted soils), and excessive or unnecessary applications (especially in healthy, fertile soils).In addition, many organic nutrient sources provide far more P relative to N and K than crops need; thus it can be challenging to meet nutrient needs precisely in an organic system. Crop harvest, especially vegetables, remove only a fraction of the P that is typically recommended in a standard soil test, and that are provided in a moderate amount of compost or organic fertilizer.

Some common pitfalls are:

* Assuming that the organic principle of “feeding the soil” will meet all of the crop’s nutrient needs without fertilizer. This approach commonly results in low, N-limited yields, especially in newly transitioning fields where soil health is not yet optimal.
* “Input substitution” – trying to get the nutrients recommended on a standard soil test from NOP allowed sources calibrating rates based on N, P, and/or K content. The organic fertilizers are more expensive and may or may not pay for themselves in increased marketable yields.
* Using compost or manure to meet crop N needs is likely to build up excess P, especially if rates are based on “available N” (estimated at 10-25% of total compost N, and 50% of total manure N).

The fourth approach is to bring soil nutrient levels to near optimum ranges (“high” or “optimum” on a soil test, but *not* “very high,” especially for P or for soluble N) and then simply ensure that nutrients harvested off are replenished sufficiently to avoid soil nutrient depletion. Compost and manure rates can be adjusted to replenish P, additional N fixed by legumes in the rotation, and K supplemented as needed (organic mulches, potassium sulfate). Sometimes, recovery of subsoil K reserves by cover crops can sufficiently replenish K.

Slide 53 – *Why soil labs recommend so much NPK*

The soil test is a double edged sword – not having it done increases production risks, yet taking the report and recommendations too literally can increase costs and risks as well.

The standard soil test can help identify pH issues (need for lime), and potential nutrient deficiencies (“low” or “very low” ratings), surpluses (“very high”) or imbalances. For example, a depleted soil poor in organic matter and biological activity may be very low in P and K, or very high, depending on field history – these two scenarios require different restoration strategies.

In this example from an organic vegetable farm in Floyd County, VA, the soil test indicates ideal pH, a “high” level of P (considered optimum, crop yield unlikely to respond to added P), a “very high” level of K (ample, possibly excessive), a low boron (B) level of 0.4 ppm, and sufficient levels of all other nutrients (not shown). Low B can affect tomato yield or quality, and a boron supplement is warranted.

Soil tests can also be misleading. Both lab procedures and interpretation protocols have been developed for conventional production systems, based on research in soils managed with synthetic fertilizers, and may not accurately reflect crop needs in organically managed soils.

In this example, the lab recommended 100 lb phosphate (44 lb elemental P) and 50 lb potash (42 lb elemental K) for tomato, as well as 90 lb N (a standard recommendation for tomato independent of soil test report, which does not include soluble N). Historically, these “maintenance” applications have been considered essential for replenishing nutrients harvested off or lost to leaching or immobilization (tieup in soil minerals or organic matter) and sustaining long term productivity. However, with a low probability of any crop need for, or response to, the P and K, their application at this time may be an unneeded expense that adds to risks of a negative cash flow. In addition, “very high” nutrient levels can present risks to soil, crop, and livestock health; for example excessive K can promote blossom end rot in tomato and life-threatening grass tetany in grazing livestock.

Several factors contribute to higher NPK recommendations than healthy soils actually need. The biggest is that the role of soil life has historically been ignored in estimating crop access to nutrients – an omission that is now being corrected as the roles of soil life and soil health become widely embraced by mainstream agricultural professionals, especially NRCS and Extension. Second, soil tests measure only the top six inches of soil, while plant roots typically extend 2 to 5 feet down. Soil is assumed to be “leaky” (which is true for depleted soil, less so for healthy soil), and the potential for deep rooted crops to retrieve nutrients is ignored.

Slide 54 – *Living soil changes everything*

Fertilizer trials were conducted over a five-year period with a corn-soy-wheat rotation with high biomass winter cover crops on an Orangeburg loamy sand soil in the coastal plain of South Carolina that initially tested sufficient in P and K. Full crop yields were sustained at half the recommended N rate, regardless of whether any P or K were added at all.

Dr. Kloot noted that most soils, especially southeastern US coastal plain soils, have large subsoil K reserves that cover crop roots readily retrieve. This may explain the stable soil test K despite significant net withdrawals through harvest. Dr. Kloot cited several farmers in a diversity of locations (NC, ND, IL, OH) who have greatly reduced fertilizer inputs and maintained high grain yields by building soil health with high biomass cover crops.

References:

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Slides 55 and 56 – *Input frugality*

Simple field trials can be used to assess whether and how much N, P, K, or other nutrients are needed for optimum production, and can also be used to test other amendments. Organic input vendors offer an ever-growing plethora of microbial inoculants, biostimulants, biochar, humates, and other amendments claimed to improve soil health and fertility, enhance crop nutrition and yield, or ward off plant pathogens and pests. Try them out in small comparison trials for two or three seasons before investing in sufficient material to treat the whole farm.

Crop foliar nutrient analysis is a valuable and often under-utilized tool for determining actual crop needs for nutrient inputs. Take samples from both healthy, productive crops, and from “hungry” or unhealthy crops of the same or different species and cultivar to help pinpoint nutrient limitations.

Slide 57 – *Resources*

More in-depth information and additional resources can be found in the new OFRF publication, *Building Healthy Living Soils for Successful Organic Farming*

*in the Southern Region*, to be released in 2021.