Nutrient Management for Crops, Soil, and the Environment
Research-based Practical Guidance for the Western Region

eOrganic Soil Health and Organic Farming Webinar Series
October 24, 2018
Developed and presented by Organic Farming Research Foundation, with funding from Western Region SARE program

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

Slide 1 – *title slide*.

Slides 2 and 3 – *2016 NORA priorities identified by Western region respondents*

A total of 555 organic farmers from the Western region participated in OFRF's 2015 survey to identify top research priorities.

Slide 4 – *Soil health and crop nutrition*

From its origins in the early 20th Century, the organic movement has emphasized *feeding the soil life* – with compost, green manures, livestock manure, and other organic residues – as the primary means to provide for crop, livestock, and human nutrition. In addition, early organic practitioners sought to meet the majority of nutrient needs from on farm sources through efficient nutrient cycling within the farm ecosystem.

Slide 5 – *Nutrient dynamics in living soil*

In natural ecosystems and in agricultural fields with healthy, living soils, the soil life or soil food web plays a central role in the conversion of nitrogen (N) and other nutrients in plant and animal residues, organic and natural mineral fertilizers, and other soil amendments into forms available for uptake by plant roots. Soil organisms also mediate a two-way flow between the pool of soluble (plant-available) nutrients and the soil organic matter, which serves as a nutrient storehouse. In addition, the soil life and plant roots work together to gradually bring insoluble, mineral-fixed phosphorus (P), potassium (K), and other nutrients into circulation through biological weathering of soil minerals.

Slide 6 – *Two way exchange between plant and soil*

Plant nutrition is a two way exchange, in which photosynthesis provides a vital source of nourishment for the soil life, in the form of root exudates and root residues. In addition to sugars, amino acids, and other simple organic compounds that directly feed soil microbes, the roots of each plant species secrete other substances that act as specific chemical signals to stimulate and host those soil organisms most beneficial to that plant. In turn, the resulting root zone microbiome facilitates uptake of the nutrients the plant needs to thrive.

The 10% of photosynthetic product delivered to soil life shown in the schematic is a conservative estimate; literature reports range from 5 to 50%, with may in 20-30% range.

Slide 7 – *Nutrient dynamics when soil health is poor*

The direct "feed the plant" approach of 20th century conventional agriculture relied on soluble fertilizers to meet crop needs. At that time, the role of soil life in soil fertility and crop nutrition was not widely understood. Soil life was largely disregarded, and often went hungry as a result of inadequate inputs of organic residues, and long fallow periods in the rotation.

Crops can suffer nutrient deficiency when nutrients are in short supply, when the soil life is depleted and unable to help plant roots access nutrient reserves, or when soil compaction restricts root growth. In degraded soils, all three conditions can occur together.

Soil life and soil organic matter play central roles in organic production, and their importance in sustainable nutrient management are now gaining wider recognition throughout 21st century mainstream agriculture. As a result, a growing body of research based information now exists to help farmers adopt soil health-based approaches to nutrient management.

Slide 8 – *Feedback: soil health and crop nutrients*

Managing for soil health builds the capacity of the soil life to nourish crops. Fertilizers further supplement crop nutrition and can be important for sustaining economically viable yields. However, nutrient sources that rapidly release soluble nitrogen and phosphorus – including poultry litter, blood meal, and succulent legume green manures as well as synthetic fertilizers – can inhibit mycorrhizal fungi and some other soil organisms, and stimulate the breakdown of soil organic matter. This can reduce the soil's long term capacity to provide for crop nutrition and increase reliance on applied nutrients in future seasons.

The high salt content of soluble fertilizers and some concentrated organic fertilizers (e.g., poultry litter, guano) can also stress soil life and plant roots.

Slide 9 – *How soil life and soil organic matter hold and deliver nutrients to plant roots.*

As soil life converts plant residues, manure, and other organic inputs into active and stable organic matter, most of the nitrogen, phosphorus, sulfur, boron, and some micronutrients in the residues become integral parts of the organic matter. They are slow-released to plants through further action of soil organisms on the active fraction – N in the form of nitrate (NO_3^-) anion and ammonium (NH_4^+) cation, P as phosphate anions, S as sulfate anion, B as borate anions, and other micronutrients as ions or chelated with soluble organic substances.

Potassium, calcium, magnesium, sodium, and some micronutrients are released from residues into the soil as soluble cations (positively charged). Negative charges on stable organic matter contribute to the soil's *cation exchange capacity* – its ability to adsorb and hold the cations in a plant-available yet not readily leachable form.

The capacity of the soil life to provide for crop nutrition through these processes is a key attribute of healthy agricultural soils.

Slide 10 – *To maintain soil fertility, organic farmers feed the soil life a diverse, balanced diet*

The "staple" item in the soil biota's diet consists of the root exudates and residues of plants grown in place – in agriculture this consists of the total biomass and biodiversity of the crop rotation including cash, cover, and sod crops. Manure, compost, and organic mulches play a supplemental and complementary role, often working synergistically with *in-situ* plant biomass to build long term soil fertility. Materials with varied carbon:nitrogen (C:N) ratios ranging from low (manure, legume green manure) to moderate (mixed species cover crops, finished compost) to high (straw or leaf mulches, corn residues) provide the best nourishment for the soil food web and build the most organic matter.

Slide 11 – *Soil testing*

Standard soil tests offered by Extension and private labs can help organic growers identify nutrient deficiencies and imbalances, and liming needs. Additional tests designed to support best soil and nutrient management are coming into more widespread use in recent years.

Soil test reports do not routinely include nitrate-N or total PAN, because soluble N levels fluctuate widely with season, rainfall, nutrient inputs, and plant uptake. However, field corn growers often use a "pre-sidedress nitrate test" (PSNT, total soil nitrate surface to 12 inches, sampled when the corn has about five leaves) to determine whether and how much additional N to apply. Pacific Northwest Extension services have adapted the PSNT for vegetable crops, using early-season soil nitrate-N levels to estimate needs for additional N.

Several protocols have been developed for estimating soil microbial activity, active soil organic matter, and the soil's capacity to mineralize (release) PAN during the course of the season. Examples include the Solvita soil respiration test, also known as potentially mineralizable carbon (PMC), permanganate-oxidizable organic carbon (POXC), and potentially mineralizable nitrogen (PMN). While not yet routinely included on standard soil test reports, these soil biology tests can be obtained through some labs.

Cornell University offers a Comprehensive Assessment of Soil Health that includes moisture holding capacity, surface and subsurface compaction, aggregate stability, total SOM, POXC, soil respiration, and indices of mineralizable N as well as standard soil nutrient analysis and texture analysis (used to fine-tune interpretation of other parameters).

Slide 12 – *Applying soil test results to organic systems*

Historically, nutrient recommendations in standard soil test reports have been based largely on research conducted in and for conventionally managed systems. Recommended rates for conventional fertilizers can be hard to "translate" into accurate recommendations for organic nutrient sources, owing to the complex nature of biologically-regulated nutrient cycling. The amount and timing of plant-available nutrient release from organic and natural mineral sources depend on many factors including region and climate; soil type, texture, and mineralogy; soil biology and soil health; and the chemical and biological makeup of the materials applied.

Nutrient cycling may be more efficient on healthy, organically managed soils, so that less nutrient input is needed; yet organic materials usually release nutrients more slowly than soluble fertilizers, so that more needed to deliver same level of available nutrients. In recent years, some soil labs are taking greater account of the central role of soil life in crop nutrition, and are modifying their approach to fertilizer recommendations for organic and non-organic producers.

Slide 13 – *Applying soil test results to organic systems*

A "high" soil test value for a given nutrient usually indicates a sufficient level for the crop to realize its full yield potential. Usually, soil labs recommend a "maintenance" application to ensure season long sufficiency or replenish nutrient removed in harvest.

A "low" soil test value for a given nutrient indicates a high probability that the nutrient level is yield limiting; a relatively high application rate is recommended to remedy the deficit.

However these recommendations are based on research conducted in conventionally managed soils, often with suboptimal levels of biological activity and overall soil health. Additional research is needed to elucidate fertilizer rate responses of crops growing in organically managed, biologically active soils. Some organic producers use lower-than-recommended nutrient input rates, based on the hypothesis that mycorrhizal fungi and other beneficial organisms reduce crop needs for fertilizer despite a "low" soil test value. While anecdotal evidence in support of this hypothesis exists, it merits rigorous evaluation through research.

Business-savvy farmers aim for the most *economically advantageous* nutrient application rates, or the threshold at which the value of additional yield no longer exceeds the cost of the additional fertilizer. This usually occurs where the yield response curve begins to level off, somewhat below the fertilizer rate at which maximum yield occurs.

Another threshold to consider is the rate at which the fertilizer begins to adversely impact soil health, water quality or greenhouse gas emissions. This may or may not be lower than the "economic threshold".

Organic producers test their soils every few years to monitor trends in nutrient levels, pH, organic matter, and cation exchange capacity. Some additional tools that can help organic farmers fine-tune nutrient inputs include:

- Their own observations of the overall health of their soil and crops.
- A crop foliar nutrient analysis. This is an excellent tool for getting a better understanding of the crop's nutritional status, and for identifying actual limiting factors (deficiencies or excesses). Foliar tests are often used by both conventional and organic fruit growers, and foliar testing merits more attention as a nutrient management tool for organic production of vegetables and field crops.
- A simple side-by-side comparison trial in which a crop is grown with *versus* without an organic fertilizer, or with two or more rates of N or other nutrient. Comparing crop performance in different treatments can help fine-tune soil test interpretation and nutrient inputs, which can save money and/or water quality in future years.

Slide 14 – *Organic soil management: a balancing act*

Research has shown that integrated organic soil management – diverse rotation, cover crops, organic amendments, and lower-impact tillage practices - can enhance both mineralization and SOM stabilization processes simultaneously.

Hurisso, T. T., S. W. Culman, W. R. Horwath, J. Wade, D. Cass, J. W. Beniston, t. M. Bowles, A. S. Grandy, A. J. Franzluebbers, M. E. Schipanski, S. T. Lucas, and C. M. Ugarte. 2016. *Comparison of Permanganate-Oxidizable Carbon and Mineralizable Carbon for Assessment of Organic Matter Stabilization and Mineralization.* Soil Sci. Soc. Am. J. 80 (5): 1352-1364.

Lori, M., S. Symnaczik, P. MaEder, G. De Deyn, A. Gattinger. 2017. *Organic farming enhances soil microbial abundance and activity – A meta-analysis and meta-regression*. PLOS ONE | https://doi.org/10.1371/journal.pone.0180442 July 12, 2017, 25 pp.

Slide 15 – *How organic producers use nutrient inputs*

More concentrated organic and natural mineral nutrient sources play a supplemental role, and are used according to soil test results, specific crop needs, and nutrient budgets for organic systems. Used judiciously, they can play a vital role in sustaining economically viable crop yields, and can be compatible with soil health.

USDA organic-allowable nutrient sources shown include (clockwise from top left): blood meal for fast-release N, kelp meal (micronutrients and a little K), mined potassium sulfate, fish emulsion, borax (for the micronutrient boron), and seaweed extract. Other amendments not shown here but frequently used in organic systems include: composted or heat processed poultry litter (concentrated NPK), liming materials (calcitic and dolomitic limestones), elemental sulfur (to lower pH), feather meal (slow-release N), colloidal rock phosphate (slow-release P), and sul-po-mag (for K, Mg, and S).

Sustaining satisfactory yields in heavy N feeders such as field or sweet corn, head brassicas and some other vegetables can require concentrated N sources such as poultry-litter based fertilizers (if soil P is low), or blood meal, feather meal, or Chilean nitrate (if soil P is high).

Slide 16 – *Goals of organic nutrient management*

This is our proposed summary of the goals of sustainable organic nutrient management, based on NRCS and NOP nutrient management standards, further informed by the economic viability and environmental stewardship goals of experienced organic producers.

During transition from conventional production or restoration of depleted soils, additional inputs may be needed to sustain yields, and to address nutrient or pH issues identified by the soil test. Once nutrient levels reach optimum ("high") ranges, inputs should approximately replenish nutrients removed in harvest. Drawing down nutrient surpluses ("very high") by applying less than the amounts removed will also improve soil health and nutrient cycling, water quality, and the farm's cash flow.

General note regarding Slides 17 and 18:

This is just a sampling of the tremendous diversity of soils, climates, and agro-ecoregions within the Western SARE region, and is admittedly a gross oversimplification. For example, the "semiarid" category includes regions in which the limited rainfall comes mostly as winter rains or snows (eastern WA and OR), or as brief intense summer thunderstorms (MT).

The NRCS has published an excellent resource that gives more precise and in-depth data, Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin, available at
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053624.

Slide 17 – *Nutrient management challenges for organic growers in the Western region*

Climates throughout much of CA, WA, OR, and ID are characterized by sufficient to excessive rainfall in winter and no or limited rain in summer. Soils are generally fertile (Mollisols, Alfisols, Andisols), and very high vegetable or grain yields and good net returns are often realized. Soil management challenges relate to moisture limitation and need for irrigation in summer, and nutrient losses through leaching during winter. With long production seasons, it can be difficult to fit winter cover crops into the rotation, yet leaving fields in bare fallow over winter can exacerbate nutrient losses, groundwater pollution, and soil compaction.

The unique mineralogy of volcanic ash-derived soils (Andisols) retains organic matter and promotes good tilth, but also has a very high capacity to "fix" phosphorus; thus greater P inputs and/or other measures to maintain crop P nutrition may be needed.

These regional generalizations are based on descriptions and geographical distributions of soil orders and suborders in Brady and Weil, Nature and Properties of Soils.

Slide 18 – *Nutrient management challenges for organic growers in the Western region*

The greatest challenge in moisture limited regions is the tradeoff between soil health maintenance (cover crops, year round plant and/or residue cover) and moisture availability to cash crops, which can be reduced by an immediately preceding cover crop. Multiple studies have shown that the traditional wheat-fallow rotation (one wheat crop every two years, soil kept in bare fallow with herbicides and/or tillage for 16-18 months between wheat crops) degrades SOM and soil health, even in no-till systems. Annual cropping systems that add either a cover or a production crop in the "off year" improves soil health and moisture-holding capacity in the long run, but often compromises wheat yields, at least in the first few years.

Some studies have found legumes, buckwheat, and rock phosphate ineffective for increasing P availability on alkaline, calcium-rich soils, though combining P with organic acid amendments has been reported to improve P availability.

Engel, R. E., P. E. Miller, B. G. McConkey, and R. Wallander. 2017. *Soil organic carbon changes to increasing cropping intensity and not-till in a semiarid climate.* Soil Sci. Soc Am. J. 81:404-413.

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

Norton, J. B., M. B. Press, and J. P. Ritten. 2014. *Marketing Opportunities and Constraints Confronting Organic Farming Operations in the High Plains.* Proposal and Final Report for OREI project 2009-01436. CRIS Abstracts.

Most soils in the desert southwest have developed over the millennia under arid conditions with active plant growth restricted to at most three months of the year. As a result, these soils have low organic matter and biological activity, low inherent fertility, and often poor structure, surface salt accumulations, or extreme nutrient imbalances. Crop production depends on irrigation, which can entail additional salinity-related challenges. Organic practices for building soil health may need to be modified or adapted for arid region soils.

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

Slide 19 – *Western region: diversity of climates and soils*

A wide range of crops and agricultural enterprises is grown in each of the major agro-ecoregions. Soil and nutrient management for organic production will look very different for each region and crop mix, and cannot be covered in full in one webinar.

The rest of this presentation will focus largely on vegetable production in Pacific Northwest and California (maritime and Mediterranean climates), and will touch briefly on dryland cereal grain production in semiarid climates.

Slide 20 – *Nitrogen challenges*

Nitrogen is especially challenging to manage because organic N sources must undergo mineralization by soil life to become plant available. The amount and timing of N release from

organic materials – even those rich in N such as legume green manure or poultry litter – can be difficult to predict, budget, and synchronize with the course of crop development.
Early in spring when the soil is cool, even the healthiest soils may not mineralize N fast enough for heavy feeders like field corn, spinach, or head brassicas.

Slide 21 – *Nitrogen and soil health: potential tradeoffs*

Maintaining high PAN levels from any source (organic or conventional) can accelerate losses of SOM, reduce the soil's future capacity to mineralize plant-available N from organic matter and inhibit beneficial plant-microbe interactions that facilitate plant nutrient uptake.

Wander, M., N. Andrews, and J. McQueen. 2016. *Organic Soil Fertility*. http://articles.extension.org/pages/18565/organic-soil-fertility.

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

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

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

Slide 22 – *Broccoli – a heavy feeder that responds well to organic N fertilizer*

Washington State U conducted broccoli trials at three maritime and two interior semiarid sites, with feather meal (11-0-0) applied at 0-240 lb/ac (2016) or 0-480 lb N/ac (2017). Seven site-years provided yield data; one of these showed yield plateau at 150 lb/ac, the others at >200. Even the lowest response (11 lb broccoli per lb N) gave a four fold return on fertilizer cost.

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

Feather meal was broadcast; band application in crop grow zone might have enhanced nutrient use efficiency (Doug Collins pers. commun.)

.

Slide 23 – *Modelling soil and environmental impacts in organic broccoli*

Field trials at University of California Santa Cruz provided the basis for modeling studies of broccoli yield and soil C and N dynamics in response to 0, 75, 150, and 225 lb N/ac in the form of blood, meat, and feather meals, with or without compost or legume-cereal cover crop prior to the broccoli. In other trials with organic rotations of broccoli followed by strawberry, 260 lb nitrate-N per acre remained in the soil, some of it mineralized from broccoli residues. Most of this N leached during winter rains (~ 18 inches over a three month period).

Nitrous oxide is a powerful greenhouse gas, and each lb N lost as N_2O negates about 130 lb carbon sequestration.

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

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

Slide 24 – *Tips for building soil health while meeting N needs of heavy feeders.*

In Washington State field trials in Puyallup, long term organic vegetable rotations receiving finished compost made from manure, bedding, and yard waste at 6 – 8 tons/ac-year accrued significantly more active and total soil organic matter than the same system amended with poultry litter containing the same amount of N (1.8 – 2.7 tons/ac-year). The compost amended soil also developed a greater capacity to provide slow-release N through the growing season. Many growers use in-row drip fertigation to deliver nutrients.

Organic grower Kat Johnson of Fields Edge Farm in Floyd, VA uses the simple strategy of broadcasting feather meal and poultry litter fertilizer just before running the bed shaper, which effectively moves the amendments into the "grow zone" – the tops of the beds. Because the root systems of head brassicas develop limited lateral extent, concentrating nutrients in and near the crop rows might enhance nutrient use efficiency.

Organic farmer and author Anthony Flaccavento of Abingdon, VA grew a summer cover crop of pearl millet + cowpea to high biomass, mowed, solarized with clear plastic for two days in the heat of August, then removed the plastic and no-till planted fall broccoli and cauliflower. Without any added N, this treatment gave excellent yields, slightly higher than a tilled bed receiving 180 lb/ac N in organic fertilizers.

Opaque tarps for 2-4 weeks on no-till managed covers have also given good yields in organic cabbage and winter squash in New York and Maine.

Research questions:

- Can this success with solarized or tarped no-till covers be repeated in the Western region?
- How does N leaching from solarized or tarp-terminated covers compare with N leaching from applied organic fertilizers?
- Can broccoli be bred for improved N use efficiency to save fertilizer costs and water quality?

Bhowmik et al., 2017. Cited above.

Maher, R., A. Rangarajan, M. Hutton, B. Caldwell, M. L. Hutchinson and N. Rowley. 2017. *Comparison of Reduced Tillage Practices for Small-Scale Organic Vegetable Production.* Special Session Symposium--Organic Agriculture Soil Health Research, TriSocieties meeting, Tampa, FL, October 2017. http://articles.extension.org/pages/74555/live-broadcast:-organic-soil-health-research-special-session-at-the-tri-societies-conference

Slide 25 – *Nitrogen is challenging for all farmers …*

Crops rely on the pool of PAN (nitrate-N + ammonium N), which can be replenished with soluble fertilizers or via N mineralization from organic amendments and active SOM. Mineralization is a process mediated by the soil life, which thus acts as the "gate-keeper" in nitrogen cycling in organic systems.

PAN from any source is subject to leaching and denitrification, and the associated environmental risks increase with the size of the PAN pool, whether from soluble fertilizer or from heavy inputs of organic N sources.

Slide 26 … *especially when soil life is depleted.*

When the soil life and pool of active SOM are depleted, the "gate keeper" becomes "stingy", providing little PAN, and reducing the efficacy of organic amendments in meeting crop N requirements. Compensating with increased N applications will increase leaching and denitrification losses. In addition, bare fallow during the winter rainy season puts the soil life on a starvation diet, thereby aggravating N losses at a time when no living plant roots are present to retrieve the nitrate before it reaches groundwater.

Slide 27 – *Matching N release to crop demand*

N demand in most annual crops goes through three distinct phases; a "lag" period during the first 3-4 weeks after planting when crop N needs are relatively small, a vegetative phase of rapid plant development and high N demand, and a maturation phase, during which N uptake slows as N is translocated from leaves to developing fruit, grain, or tuber.

N use efficiency is maximized when the release of PAN from fertilizers, amendments, and soil organic matter is synchronized with the period of high N demand. If N is released too quickly (for example, after a pre-plant application of the entire season's recommended N in fast-release forms), early season rains may leach it out before the crop can utilize it. If amendments or residues release N too slowly, the N becomes available only after the crop has entered the maturation phase, resulting in crop N limitation and risk of late season or post-harvest leaching.

Organic nutrient management seeks to avoid the "too fast" scenario and match the timing of PAN to crop needs through biologically mediated, slow-release sources like cover crops, compost, and a large pool of active soil organic matter. However, an organic fertility program that provides ideal crop N nutrition in warm, moist, aerobic, biologically active soil may release N too slowly in cold, wet, or hot dry years, or if soil life and soil health are below par.

Conventional growers often split N inputs, with a small amount of N in a pre-plant starter fertilizer, and the rest in one or two N sidedress applications during the vegetative growth stage. This improves N use efficiency and reduces leaching losses. Organic farmers sometimes use a similar strategy with post-plant applications of faster-release organic N sources. However, managing the timing of organic N sources is inherently more challenging than with the "known quantity" of conventional synthetic N.

The graph is a conceptualized summary of information provided in Oregon State U. Extension bulletin EM 9165, *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon*, by D.M. Sullivan, E. Peachey, A.L. Heinrich, and L.J. Brewer, May, 2017.

Slide 28 – *Asynchrony of N supply and N demand in organic strawberry*

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

Strawberry is a major crop in California, accounting for 85% of US production. 9% of CA strawberry acreage is organic. Strawberries are grown in coastal regions of central CA, where mild, dry summers allow prolonged harvests and high yields.

N management is especially challenging because of the very long lag phase in the crop's N utilization, which often renders preplant applications of organic N sources ineffective. The strawberry crop in this diagram, planted in November after incorporation of broccoli, was unable to utilize some 260 lb nitrate-N mineralized from broccoli residues and pre-plant organic fertilizer. Winter rains leached most of this N out of the root zone long before the strawberry crop began taking up much N in late spring. Preplant N from other sources such as summer cover crops and compost is similarly mineralized and lost during the winter.

Efforts to deliver N to organic strawberries in spring and summer via drip irrigation encountered technical problems, as fish emulsions and other liquid organic N fertilizers tend to clog filters or emitters of drip irrigation systems. The research team is testing some newer formulations that may be less apt to clog drip lines.

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.

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

Slide 29 – *Delivering N where it is needed*

What if the "gatekeeper" of soil life could deliver soluble N *directly* to plant roots as they need it, without flooding the bulk soil with soluble N that would be subject to leaching and denitrification? In nitrogen fixing legumes, the *Rhizobium* symbiosis performs this function. Can other soil organisms help other plants access the large store of organic N by delivering just the right amount to their "doorstep"?

Research evidence suggests that this can happen:

- Rhizosphere (root zone) microbial population densities are typically 10 times those of bulk soil.
- Plant roots give off chemical signals that attract the "right" microbes into their vicinity, then feed them with nourishing root exudates. In turn, the microbes help the plants acquire the moisture and nutrients they need, increase plant resilience to stress, and ward off disease organisms.
- Some of these beneficial organisms actually live inside the root tissue (endophytes); others live on or near the root surface. Arbuscular mycorrhizal fungi (AMF), a vital component of the microbiome of most crops, grow into root tissue and out into the soil, effectively expanding the root system several-fold and enhancing uptake of moisture, N, P, and micronutrients.
- Some warm season grasses, including pearl millet and traditional land races of field corn support N fixing bacteria in their root zones, through which they can meet 10 to 50% of their N requirement.

The phenomena depicted here have been called "tightly coupled nutrient cycling." Plant geneticists and breeders have gathered evidence that crops can be selected for greater efficacy in forming these nutrient cycling relationships with soil life in their root zones.

Slide 30 – *Tightly coupled N cycling in organic tomato*

Can soil-plant-microbe interactions give high yields and minimize N leaching? UC Davis researchers studied 13 organic tomato fields in Yolo County and found three distinct patterns: N limited, N saturated, and tight N cycling (a win-win for crop yield and water quality).

The fields with the tightest N cycling also had the highest levels of active and total soil organic matter, and high level of microbial enzymes involved in N mineralization. While crops received some in-row soluble N as fish emulsion or Chilean sodium nitrate, the bulk soil was amended with a yard waste compost with a moderate C:N ratio (15-18:1) and slow release of N.

N saturated fields generally received more total organic N input, and from lower C:N sources such as guano, poultry litter fertilizer, and all-legume cover crops. Overall biological activity was similar to the tightly coupled fields, but with more enzyme activity associated with SOM breakdown and less activity related to N mineralization.

N deficient and tight N cycling fields both had soil nitrate-N low enough to suggest crop N limitation, but activity levels of plant root enzymes in the tight N cycling fields were similar to the high-N fields, indicating crop capacity to access N from organic sources in the soil.

UC Davis researcher Louise Jackson states in her 2013 report: "Since genetic pathways regulating N uptake are highly conserved across plant species, studies on these N metabolism genes in a model plant such as tomato are highly relevant to other crops."

Bowles, T. M., A. D. Hollander, K. Steenwerth, and L. E. Jackson. 2015. *Tightly-Coupled Plant-Soil Nitrogen Cycling: Comparison of Organic Farms across an Agricultural Landscape*. PLOS ONE peer-reviewed research article. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0131888.

Numerous other articles available at http://ucanr.edu/sites/Jackson_Lab/.

Jackson, L. 2013. *Researcher and Farmer Innovation to Increase Nutrient Cycling on Organic Farms.* Proposal and final report for OREI project 2009-01415. CRIS Abstracts.

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.

Slide 31 – *Managing for tightly coupled N cycling*

The UC Davis research team attributed the tightly coupled N cycling partly to existing soil conditions (soil type and past history that promoted soil health), and partly to current season management practices. Other research has shown that mycorrhizae build SOM and enhance the capacity of crops to absorb and utilize N from organic amendments and SOM. Mycorrhizal fungi in legume roots can enhance N fixation by the *Rhizobium* in a three-way symbiosis.

Hamel, C. 2004. *Impact of arbuscular mycorrhizal fungi on N and P cycling in the root zon*e. Can J Soil Sci. 84(4):383-395.

Rillig, M.C. 2004. *Arbuscular mycorrhizae, glomalin, and soil aggregation.* Can. J. Soil Sci. 84(4): 355–363.

Drinkwater, L. E. 2011. *It's Elemental: How Legumes Bridge the Nitrogen Gap.* The Natural Farmer, Summer 2011, Special Supplement on Legumes as Cover Crops. www.nofa.org/tnf/Summer2011B.pdf.

Slide 32 – *Other zone-management strategies*

Research findings from outside the region:

Cover crops and tillage can also be managed to concentrate PAN in the crop root zone where it will be utilized most efficiently.

Researchers at Lincoln U, Missouri, funded through a 2017 OREI grant, are evaluating an experimental organic no-till system in which two rows of radish are planted in the crop row, with the rest of the field in rye + vetch. The radish is expected to winterkill and its rapidly-decaying residues will leave a nutrient rich, easily-prepared seedbed for the cash crop when the rye+vetch is mowed, roll-crimped, or terminated by opaque tarp. Later in the season, the no-till terminated rye + vetch provides slow-release nutrients as the root zone of the growing cash crop expands. While radish may not winterkill in Mediterranean climates, and is not a good choice ahead of head brassicas, it may be readily managed by strip tillage ahead of tomato or other summer vegetables.

Reference: Pinero, J. C., Z.E. Mersha Ayele, and T. E. Eaton. 2017. Scale-appropriate strategies: cover crop based no-till systems for small vegetable farmers. OREI project 2017-02428, proposal, CRIS Abstracts.

In ridge tillage, a high residue cultivator is used several weeks after crop emergence to rebuild ridges, knock out weeds, and move some of the organic residues into crop rows. Researchers in the Midwest confirmed that ridge tillage concentrates mineralization in the crop row and enhances active and total SOM compared to conventional tillage. The investigators coined the term "soil functional zone management" (SFZM) for this strategy.

Reference: Williams, A., A. S. Davis, A. Jilling, A. S. Grandy, R. T. Koide, D. A. Mortensen, R. G. Smith, S. S. Snapp, K. A. Spokas, A. C. Yannarell, and N. R. Jordan. 2017. *Reconciling opposing soil processes in row-crop agroecosystems via soil functional zone management*. Agriculture, Ecosystems, and Environment 236: 99-107.

Slide 33 – *The challenge of phosphorus in organic nutrient management*

Many organically-managed soils have elevated P levels, especially when manure or compost are major sources of organic matter and fertility. For example, three of the five farms in the Washington State broccoli study cited above had excessive soil P levels.

Even when good soil management maintains sufficient micronutrient levels and protects water quality, soil test P levels in the "very high" (surplus) range can significantly reduce the activity of mycorrhizal fungi. In one study, conventionally managed corn and soybean crops actually had higher levels of mycorrhizal fungal colonization than the same crops organically grown, a phenomenon attributed to the elevated P levels in the latter system, which utilized poultry litter for N.

Rillig, M.C. 2004. and Hamel, C. 2004. Cited above.

Hu, S., C. Reberg-Horton, M. Schroeder-Moreno, Y. Cardoza, J. Grossman, W. Robarge, and W. Eveman. 2015b. *Assessing the Greenhouse Gas Mitigation Potential of Organic Systems in the Southeast.* Progress report for ORG project 2012-02978. CRIS Abstracts.

Slide 34 – *Replenishing nutrients: vegetable crops*

Nutrient replenishment should aim to balance inputs with exports through harvest to maintain optimum levels ("high" but not "very high" or "excess" on soil tests). The table shows typical yields, nutrient removal rates, and recommended fertility inputs when soil tests show "high" P and K levels for five vegetable crops in western Oregon; and comparison with the nutrients delivered by typical organic nutrient sources. This clearly illustrates the challenges that organic producers face in managing soil P for optimum soil life and health.

Earlier Oregon State U Extension bulletins recommended maintenance inputs of 17 – 39 lb P (40 – 90 lb P_2O_5) and 33 – 50 lb K (40 -60 lb K_2O) for "high" soil test P (40 – 100 ppm on Bray 1 P for maritime soils, or 25 – 50 ppm on Olsen P test for dryland soils) and K (150-250 ppm on ammonium acetate extraction). With increased recognition of the role of soil life, and potentially negative impacts on soil, crop, and livestock health of excessive nutrient levels, recently updated bulletins for snap bean and onion recommend *no* P or K when soil test levels are high, and keeping P inputs *below* anticipated harvest removals for all crops.

N recommendations shown here are for *total* plant available nitrogen (PAN) from all sources. To determine how much additional fertilizer N to apply, Oregon State Extension recommends: subtract estimated or measured pre-plant soil nitrate-N (surface to 12 or 24 inches), estimated N mineralization from soil organic matter, estimated PAN from cover crops, compost and other amendments; and nitrate-N in irrigation water. For details on N assessments and nutrient management, see OSU Extension bulletins available at https://catalog.extension.oregonstate.edu/topic/agriculture/soil-and-water, including:

- Oregon State U. Extension bulletin EM 9165, *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon*, by D.M. Sullivan, E. Peachey, A.L. Heinrich, and L.J. Brewer, May, 2017.
- Pacific Northwest Extension bulletin PNW 646, *Soil Fertility in Organic Systems: A Guide for Gardeners and Small Acreage Farmers*, by Doug Collins, Carol Miles, Craig Cogger, and Rich Koenig, 2013.
- Pacific Northwest Extension bulletin PNW 546, Nutrient Management for Onions in the Pacific Northwest. D. M. Sullivan, B. D. Brown, C. C. Shock, D. A. Horneck, R. G. Stevens, G. O. Pelter, and E. G. B. Feibert. 2001.

Slide 35 – *Adjust amendment rates to soil test P levels*

Several studies have shown that small amounts of compost can work synergistically with cover crops and diverse rotations to build soil health and fertility. For more information, see Soil Health and Organic Farming Building Organic Matter for Healthy Soils: An Overview, available at www.ofrf.org.

Slide 36 – *Cover crops: a vital tool for organic nutrient management*

Cover crops play a central role in organic nutrient management. As a key source of organic carbon for the soil life, high biomass cover crops enhance the soil's long term capacity to provide for crop nutrition. Most legume and grass cover crops enhance mycorrhizal fungal populations, while buckwheat and crucifer covers host other beneficial soil micro-organisms.

Including N-fixing legumes in the crop rotation can meet 50-100% of N needs over the rotation. When soil soluble N levels are low, legumes are stimulated to maximize N fixation, and some warm season grasses host N-fixing bacteria in their root zone. When soil soluble N is abundant and thus susceptible to leaching or conversion into nitrous oxide, cover crops switch to "scavenging mode," absorbing and holding the surplus N for future production, thereby protecting water quality and climate.

When plant-available P and K are below optimum, cover crops can enhance their availability. Buckwheat and most legumes can retrieve P from insoluble organic and mineral sources (including rock phosphate amendments), while most grasses can unlock "mineral-fixed" K to replenish the supply of exchangeable K. Because cover crops do not "fix" P and K from thin air the way they do C and N, they will not add unneeded P and K when soil levels are already ample.

Note about Slides 37 and 38: These two slides condense and conceptualize information from dozens of research reports and extension publications, many of which are cited in the OFRF Soil Health and Organic Farming Guides on cover crops and nutrient management. This body of knowledge also provides the groundwork of nutrient management tools for organic systems, such as the Oregon State University on-line Cover Crop and Organic Fertilizer Calculator http://smallfarms.oregonstate.edu/calculator.

Slide 37 – *Cover crop types and nitrogen dynamics*

N fixation potential is maximal in high-biomass mixes in which legumes comprise 30 -50% of aboveground growth. N demand by the non-legumes stimulates increased legume N fixation. In addition, mixes are most responsive to varying soil conditions, fixing more N where soil soluble N levels are low, and scavenging soluble N scavenging where it is abundant – in effect, a biological approach to precision farming. Deep rooted grasses (pearl millet, sorghum-sudan, some perennials), crucifers (radish, canola), and some other forbs (such as chicory) can recover most soil nitrate-N to depths of 5 to 8 feet.

Note that <u>all</u> low C:N cover crops, including radish, will release soluble N rapidly when tilled in, which can pose environmental risks. A recent study suggests that nitrous oxide emissions from an all-legume plowdown can negate the carbon sequestration resulting from growing the cover crop.

Lugato, E., A. Leip, and A. Jones. 2018. *Mitigation potential of soil carbon management overestimated by neglecting N_2O emissions*. Nature Climate Change 8: 219-223. www.nature.com/natureclimatechange.

Slide 38 – *Cover crop maturity and nitrogen dynamics*

As a cover crop grows and matures, biomass and total N accrue slowly at first, and then exponentially during later vegetative growth and flowering. Young, succulent cover crops are N rich (low C:N ratio), and thus release N rapidly if terminated at this stage. C:N increases through the phases of rapid biomass accrual, flowering, and seed development and maturation.

When allowed to grow to its full height and into late flowering phase, cover crops make their greatest *total* contributions to soil organic matter, organic nitrogen, and microbial growth via root exudates and residue return to the soil. However a grass + legume cover crop mix terminated at late flowering may not release much "quick N" to the following cash crop. Yet, terminating the cover crop just four weeks earlier can cut organic matter contributions by half.

Long term soil health building through integrated organic practices with cover crops grown to maturity (flowering) can increase the delivery of crop-available N from SOM by the soil life, thereby reducing the need for "quick N" from high-N cover crops or organic fertilizers.

An all-grass cover crop terminated later than full head or pollen shed, or any cover crop allowed to mature until leaves turn brown and dry, is likely to tie up some soil N, increasing the need for N applications to the soil. In addition, the high C:N residues are less nourishing to soil life than moderate C:N (~20 - 30:1).

Slide 39 – *The dryland farmer's dilemma*

Montana State trials at multiple locations has confirmed that cover crops reduce subsequent wheat yields, mostly by reducing soil moisture reserves at time of wheat planting, and sometimes also by consuming soil N (especially non-legume covers). Yet, 30% of farmers in a recent survey use cover crops, of these, 90% plan to continue cover cropping, primarily because of observable soil health benefits. In some cases, cereal grain yields improve after several rotation cycles with cover crop, reaching or exceeding yields in the wheat/fallow system.

In a NRCS Conservation Innovation Grant project, in which 20 farmers hosted four years of on-farm trials comparing cover crop versus herbicide fallow prior to dryland winter wheat, the wheat yields after cover crop varied from unchanged to moderately (20%) improved to severely depressed (>50%) compared to fallow, depending on soil moisture levels after cover crop.

Engel et al., 2017; Miller et al., 2009 (cited above).

Jones, C., R. Kurnick, P. Miller, K. Olson-Rutz, and C. Zabinski. 2015 Montana Cover Crop Survey Results. Dept. of Land Resources and Environmental Sciences, Montana State University, 15 pp. http://landresources.montana.edu/soilfertility/documents/PDF/reports/2015CCSurveyReport.pdf.

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

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

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

Slide 40 – *Tips for organic dryland soil management*

References for the tips on this slide:

McCauley, A., C. Jones, and J. Jacobsen. 2004. Nutrient Management Module 15: Sustainable Agriculture. http://msuextension.org/publications/AgandNaturalResources/4449/4449_15.pdf.

Miller et al., 2009; Olson-Rutz et al., 2010 (cited above).

Borrelli, K., R. Koenig, I. Burke, E. Fuerst and R. Gallagher. 2011. *Nitrogen Dynamics in Nine Rotation Systems from Transition to Certification of Organic Dryland Grain Production*. ASA Annual Meeting. https://a-c-s.confex.com/crops/2011am/webprogram/Paper66429.html.

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.

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.* Outcomes of this project, including success with winter pea, are described in a 2012 blog post by Bob Hoffman, *Transitioning to Dryland Organic, People, Small Bites, Events* http://cahnrs.wsu.edu/blog/2012/04/transitions-people-small-bites-events/. ‘

Slide 41 – *Building soil fertility yet losing money: a paradox in dryland wheat*

This excellent result came from a single heavy application (22 tons dry weight per acre) in 1995 of compost made from dairy manure + straw bedding. The finished compost had a moderate C:N ratio of about 20:1.

The paradoxical finding that such dramatic soil health and crop responses to a one-time compost application did not pay for the compost results from:

- Low wheat yields (25 and 13 bu/ac with and without compost), and low value crop ($10/bu for organic wheat).

- Expensive compost ($154/ton dry weight). Researchers later located a cheaper source of compost ($46/ton dry weight), which would have given a modest net return of $300 per acre over the 16 years of the trial.

Reeve, J., and E. Creech. 2015. *Compost Carryover Effects on Soil Quality and Productivity in Organic Dryland Wheat*. http://articles.extension.org/pages/73247/compost-carryover-effects-on-soil-quality-and-productivity-in-organic-dryland-wheat.

Slide 42 – *Organic nutrient management research priorities for the Western region*

Research findings covered in this presentation illustrate the need for much more research into nutrient dynamics and crop responses to N, P, K, and other nutrients in organic systems. The phenomenon of tight N cycling – a win-win for crop yield, soil health, and water quality – documented in tomato in California, merits investigation in a wider range of crops and regions, including the potential to breed crops for tight N cycling and overall nutrient efficiency.

The broader topic of plant breeding for optimum soil health is explored in the OFRF Guide, *Soil Health and Organic Farming: Plant Genetics, Plant Breeding, and Variety Selection,* available at www.ofrf.org.

Slide 43 – *Information Resources: Pacific Northwest*

Extension bulletins published for Pacific Northwest producers include much excellent information on sustainable nutrient management for both organic and non-organic producers, addressing production, economic, and environmental stewardship goals, and adapting recommendations for maritime (west of Cascades) and interior / semiarid regions. Updated publications now take fully into account the roles and functions of the soil life in nutrient cycling and crop nutrition, especially nitrogen, and thus go far toward addressing the needs of organic and transitioning farmers.

Slide 44 - *Information Resources: Semiarid regions*

Search the Montana State U Extension site for "organic production" to obtain many other informative publications on organic soil, crop, and nutrient management.

Slide 45 – Questions?