**Nutrient Management for Crops, Soil, and the Environment***Research-based Practical Guidance for Organic and Transitioning Farmers*

eOrganic Soil Health and Organic Farming Webinar Series

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

Slide 1 – *title slide*.

Slide 2 – *Organic farmer research priorities*

 In 2015, OFRF surveyed a total of 1,403 organic producers representing all four USDA regions (Northeast, North Central, South, and West) to identify research priorities. Soil health was the most often cited priority, and nutrient management was close behind. Responses clearly indicated a desire to move beyond “input substitution” toward an ecological approach to crop nutrition based on better understanding of soil life, soil health, nutrient cycling, and crop nutrition.

Slide 3 – *Soil health and plant 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 4 – *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 5 – *Two-way exchange*

 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 the “bread and butter” of sugars and amino acids, 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.

Slide 6 – *Crop nutrient sufficiency*

 Optimum plant nutrition depends on the “soil health triangle” of favorable physical, chemical, and biological soil conditions. Soil organic matter contributes to all three by improving soil tilth, providing habitat and food for soil life, and holding reserves of slow-release nutrients.

Slide 7 – *Causes of crop nutrient deficiency*

 Crop nutrient deficiency may reflect an actual lack of the nutrient in the soil, but may also result from insufficient biological activity to unlock nutrients from soil minerals or organic residues. Restriction of root growth and depth by a subsurface hardpan or excessively acidic subsoil conditions (which can increase soluble aluminum to phytotoxic levels) can severely limit crop nutrient uptake, especially during dry spells that deplete topsoil moisture. Two or more of these conditions can occur together in soils in suboptimum health.

 While fertilizers (synthetic or organic) can remedy low levels of the nutrient itself, increased fertilizer applications in an effort to compensate for low biological activity, poor tilth, or subsoil acidity may perpetuate these problems and increase risks to water quality. Building soil organic matter through greater plant biomass and root mass in the rotation, and regular inputs of organic materials, will help address all three causes of crop nutrient limitation.

Slide 8 - *Soil health and plant nutrients*

 Long term implementation of soil health management practices such as cover cropping gradually increases the capacity of the soil life to release plant-available nutrients and thereby improve crop nutrition. Fertilizers further supplement crop nutrition and can be important for sustaining economically viable yields. However, nutrient sources that rapidly release soluble nitrogen (N) and phosphorus (P) – including poultry litter, blood meal, and succulent legume green manures as well as 10-10-10 and other synthetic fertilizers – can inhibit mycorrhizal fungi and some other soil organisms and stimulate the breakdown of soil organic matter. Repeated use of P-rich manure compost can also accrue surplus P and deter mycorrhizal activity. Surplus P and soluble N 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 such as potassium chloride and ammonium nitrate, and of some of the more concentrated organic fertilizers (e.g., poultry litter) can also stress soil life and plant roots by increasing the soluble salt concentration in soil moisture.

Slide 9 – *20th Century nutrient management*

 The direct “feed the plant” approach of late 20th century conventional agriculture relied on soluble fertilizers to bathe the crop roots in a nutrient-rich soil solution. Because the role of soil organisms in soil fertility and crop nutrition was not widely understood, the soil life was left out of the equation of crop nutrition – and often went hungry as a result of inadequate inputs of organic residues, especially during long fallow periods in the rotation.

 With soil life and soil health now gaining recognition and beginning to shape “best management practices” throughout 21st century mainstream agriculture, why dwell on the past? Because – unfortunately – many university and private soil test labs and some other service providers still base fertilizer and nutrient management recommendations on the “feed your crop from a fertilizer bag” paradigm of the mid and late 20th Century. More on this later.

Slide 10 – *Organic nutrient management. Step 1: understand essential crop nutrients*

 Essential plant nutrients – those elements that plants must get from the soil, and not via photosynthesis – include the “major nutrients” NPK, “secondary nutrients” calcium, magnesium, and sulfur, and micronutrients. Historically, conventional agriculture has focused on NPK, and these are indeed the most commonly yield-limiting and most challenging to manage. In addition to the importance of soil organic matter and soil life, the organic agriculture movement has emphasized the need to pay attention to *all* essential nutrients in crop and livestock production. Biological approaches – relying on crop rotation and cover crops for soil health, and using complex organic and natural-mineral fertility sources – promote balanced crop nutrition.

 Plant-available anions (negative charge) like nitrate-nitrogen, phosphates, and sulfate, exist mainly in the soil solution, and can easily leach out of the root zone during heavy rainfall or snowmelt. Plant available cations (positive charge) like potassium, calcium, and magnesium can also occur in the soil solution, but are mostly adsorbed (held) on the soil’s cation exchange capacity consisting of negatively charged clays and stable soil organic matter, and are thus less likely to leach, except in sandy soils low in organic matter.

 Nutrient reserves (not immediately available to plants, but potentially released through microbial and plant root biological processes) are held in soil organic matter (N, P, S) and in soil minerals (P, K, Mg, Ca, micronutrients).

Slide 11 – *Essential micronutrients*

 Soil organic matter, soil life, and soil health play important roles in providing essential micronutrients for crops and livestock. Low-solubility cations like copper, zinc, iron, and manganese become more plant available when they combine with soluble organic substances in the soil to form chelates, and when soil microbes convert them to more soluble forms and mycorrhizal fungi facilitate plant uptake.

 Boron is present as a soluble anion, and is often deficient in topsoils under warm, rainy climates. Sodium and chlorine are rarely deficient, and can be present in excess in saline-alkaline soils of semiarid regions, or in overfertilized soils, especially in high tunnels.

 Crop foliar nutrient analyses can be especially valuable for detecting subtle micronutrient deficiencies or imbalances.

 Good organic management, maintaining desirable soil pH (6.0 – 7.5 for most crops), compost made from a diverse mix of materials, and additional supplementation when indicated by foliar and soil tests can ensure optimal levels of micronutrients.

Slide 12 – *How soil life and soil organic matter hold and deliver nutrients to plants*

 As soil life converts plant residues, manure, and other organic inputs into active and stable soil organic matter (SOM), most of the nitrogen, phosphorus, and sulfur in the residues become integral parts of the organic matter, and are slow-released to plants through the action of soil life on the active fraction. Potassium, calcium, magnesium, and sodium are released as soluble cations, and 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.

 Soil organisms also feed on the active SOM itself, releasing the N, P, and S therein for plant uptake. A substantial portion of the active SOM (sometimes called “slow” SOM) turns over gradually (half-life of a few years to a couple decades), and thus serves as an important nutrient reserve in healthy soils.

Slide 13 – *Organic nutrient management. Step 2: Feed the soil life a “balanced diet”*

As with human nutrition, a key characteristic of a “balanced diet” is its diversity. Thus, feeding the soil with a variety cover crops, cash crop residues, and organic inputs supports a healthier soil food web and better nutrient cycling than feeding it the same amount of organic materials in a single form, such as rye cover crops or horse manure.

 Notice how many of the elements of a “balanced diet” for the soil life consists of plant-derived materials of varied origin, including cover crops, residues of production crops from different plant families, tree leaves, etc. Materials with varied carbon:nitrogen (C:N) ratios from low (manure, legume green manure) to moderate (mixed species cover crops, finished compost) to high (hay and leaf mulches, corn residues) provide the best nourishment for the soil food web, and enhance its capacity to mineralize nutrients from organic matter.

Slide 14 – *Organic nutrient management. Step 3: Test the soil*

 The standard soil tests offered by Extension and private labs give a “snapshot” of the chemical conditions of the soil at the time of sampling, and can provide helpful information for organic growers. Yet, soil test reports can be misleading, since lab protocols and fertilizer recommendations were designed for conventional systems. Nutrient cycling dynamics in healthy, organically managed soils differ from conventionally fertilized soils and can vary with the season as well. Thus, in some circumstances, crops growing in organically managed soils may access nutrient reserves that the soil test lab cannot “see.”

 Use the soil test in conjunction with field observation and crop foliar nutrient analysis to identify nutrient deficiencies and imbalances, including pH issues. Use repeat tests in subsequent years (use the same lab and be consistent in methods and timing of sampling) to monitor trends over time. Be aware that standard NPK fertilizer recommendations often exceed actual need – so be conservative unless experience has demonstrated that recommended rates give economically important yield benefits in a particular crop.

 The micronutrients included on the soil test vary among labs. University Extension services usually emphasize those nutrients most often deficient in the University’s state or region.

 Standard soil tests do not give nitrate-N or total soluble (plant available) N, because this number fluctuates widely with season, rainfall, amendment applications, and plant uptake. Soil nitrate tests are sometimes done for specific crops and seasons (e.g., pre-sidedress soil nitrate test on corn, or post-harvest nitrate to evaluate and fine tune N management).

 Several protocols have been developed to estimate the capacity of soil life to mineralize (release) plant-available N from organic matter. These include “potentially mineralizable N” based on a 7-day lab incubation procedure, an “autoclaved citrate extractable” (ACE) protein measurement, and other procedures for estimating decomposable organic N in the soil.

 Protocols for measuring soil microbial activity (Solvita respiration test; soil enzyme activities) and active SOM (the most reliable appears to be “permanganate oxidizable SOM” which correlates well with mineralization, SOM stabilization, and crop yields) have been developed.

 These and other measures of soil microbial activity, active SOM, and potential to release plant available N require further research and development for practical application. However, some of these tests can be obtained from some labs, either individually, or as part of a soil health assessment such as the Cornell Assessment of Soil Health CASH).

Slide 15 – *Organic nutrient management. Step 4: provide supplements as needed*

 More concentrated organic and natural mineral nutrient sources play a supplemental role, and are used according to soil and crop foliar test results, specific crop needs, and nutrient budgeting 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 K), mined potassium sulfate (K and S), fish emulsion (NPK and micronutrients), borax (for the micronutrient boron), and seaweed extract (micronutrients an growth factors).

 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 and supplement S), feather meal (slow-release N), colloidal rock phosphate (slow-release P), and sul-po-mag (for K, Mg, and S).

 Blood meal and feather meal are often used for head brassicas and other heavy N feeders, and are especially useful where soil P is already high.

Slide 16 – *Nutrient management challenge #1: translating soil test reports to “organic”*

 Nutrient recommendations on most standard soil test reports are based on research conducted in and for conventionally managed systems, with a “feed the plant” direct-fertilization approach. Much of the research underpinning today’s standard soil test recommendation protocols was done before the widespread appreciation of the central role of soil life and soil organic matter in nutrient cycling and crop nutrition. In biologically depleted, overtilled soils treated liberally with soluble fertilizers (including the fields where much 20th century nutrient management research took place), over half of applied NPK can be lost or tied up in the soil before crops can access it. As a result, recommended rates often exceed anticipated crop uptake and considerably exceed actual nutrient removals in harvest.

 Recommended rates for conventional fertilizers may not apply for organic nutrient sources owing to the complex nature of biologically-regulated nutrient cycling and nutrient release. On the one hand, nutrient cycling may be more efficient on healthy, organically managed soils (less input needed); on the other, organic materials may release nutrients more slowly (more needed to reach same level of soluble, available nutrients). In addition, depleted soils may tend to immobilize nutrients during initial phases of restoration under organic management.

 The amount and timing of nutrient delivery from organic and natural mineral sources to organic crops depends on many factors including region and climate; soil type, texture, and mineralogy; soil health including activity, diversity, and balance of the soil life; the crop being grown and preceding crops in the rotation; and the chemical and biological makeup of the nutrient sources used.

Slide 17 – *Research-based nutrient recommendations*

 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 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 when the added fertilizer begins to adversely impact water quality or greenhouse gas emissions – which may be lower, similar to, or higher than the economic threshold.

 In addition, a soil rich in organic matter and diverse beneficial microorganisms may deliver more nutrients to plants than suggested by soil test reports. (Compare purple and orange curves for “low” soil test value).

 However, in some cases, the reverse may occur; for example the N tie-up that follow incorporation of nutrient poor, high-carbon residues into biologically active soil.

Slide 18 – *Nutrient management challenge #2: Nitrogen*

 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, most biologically-active soils may not mineralize N fast enough for heavy feeding crops like field corn, spinach, or head brassicas.

 A great majority of modern crop cultivars were developed and selected in conventionally managed fields with soluble NPK fertilizers and crop protection chemicals, and may not be genetically equipped to thrive on slow-release organic nutrient sources. Several researchers have found modern cultivars less capable of associating with N fixing microbes and/or mycorrhizal fungi than older heirloom or land race lines – in other words, the capacity of crop plants to partner with the soil life for optimum nutrition has been bred-out to some extent.

 Organic breeding endeavors on various crops, funded through USDA Organic Research and Extension Initiative, have demonstrated potential for breeding crops better adapted to organic soil and nutrient management systems. This potential is explored in greater depth in a recent webinar in this series, *Plant Genetics, Breeding and Variety Selection*, now available on the eOrganic archives.

Slide 19 – *Nitrogen and soil health: potential tradeoffs*

 Organic rotationalno-till systems based on high-biomass cover crops terminated by roll-crimping or mowing often enhance soil health in comparison with either organic tilled or conventional no till. However, yields are often reduced by N limitation, weed pressure, and cash crop establishment challenges, especially in northern locations. In warmer climates with longer growing seasons, soil N mineralization in organic rotational no-till may be sufficient to sustain crop production; crop establishment challenges are also eased though weed pressure can become more intense.

 Barbercheck, M. E., D. A. Mortensen, H. Karsten, E. S. Sanchez, S. W. Duiker, J. A. Hyde, and N. E. Kiernan. 2008. Organic Weed Management: Balancing Pest Management and Soil Quality in a Transitional System. Final report on ORG project 2003-04619. CRIS Abstracts.\*

 Delate, K. 2013. Developing Carbon-positive Organic Systems through Reduced Tillage and Cover Crop Intensive Crop Rotation Schemes. Final report for ORG project 2008-01284. CRIS Abstracts.\*

 Delate, K., C. Cambardella, and C. Chase. 2015. Effects of cover crops, soil amendments, and reduced tillage on Carbon Sequestration and Soil Health in a Long Term Vegetable System. Final report for ORG project 2010-03956. CRIS Abstracts\*

 Reinbott, T. 2015 .*Identification of factors affecting carbon sequestration and nitrous oxide emissions in 3 organic cropping systems*. Final report on ORG project 2011-04958. CRIS Abstracts.\*

 Shapiro, C. 2013. *Organic Farming Systems Research at the University of Nebraska, Part 2 Nutrient Management in Organic Systems* (Webinar). <http://articles.extension.org/pages/67368/organic-farming-systems-research-at-the-university-of-nebraska>.

 Silva, E. 2015. *Implementing cover crop-based reduced tillage in small scale organic vegetable production*. 2015 Organic Agriculture Research Symposium, recording at <http://eorganic.info/node/12972>.

 Use of poultry litter (total N 120 – 180 lb/ac) in organic grain rotations in Michigan and of blood, meat and feather meals in organic broccoli in California (total N 80 – 240 lb/ac) substantially aggravated both nitrate-N leaching and N2O emissions.

 Maintaining high concentrations of soluble N from any source (organic or conventional) to maximize yields can accelerate losses of SOM, reduce the soil’s future capacity to mineralize plant-available N from organic matter and reduce or inhibit mycorrhizal associations and other plant-microbe interactions that facilitate efficient nutrient utilization.

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

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

 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>.

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

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

Slide 20 – *Nitrogen is challenging for all farmers …*

 Plants take up nitrogen mainly in the soluble nitrate and ammonium forms, thus “plant available nitrogen” or PAN = nitrate-N + ammonium N. Both conventionally and organically grown crops must have access to PAN, either directly from soluble fertilizers, or via *mineralization* of organic N in active soil organic matter, manure, and other organic amendments. Mineralization is a process mediated by the soil life, which thus acts as a “gate-keeper” in nitrogen cycling in organic systems.

 Nitrate-N from any of these sources is subject to leaching whenever heavy rainfall or irrigation results in a net downward movement of moisture in the soil; when the nitrate moves beyond the reach of crop roots, it is lost from the system and may pollute groundwater. In addition, soluble soil N is subject to microbial *denitrification* whenever soil moisture is high and aeration is limited. Denitrified N enters the atmosphere as elemental N2 gas (harmless other than the wasted fertilizer N) and N2O, a powerful greenhouse gas.

 In well managed organic systems the “gatekeeper” – the soil food web – can moderate though not eliminate these losses and environmental impacts; when heavy organic inputs build a *very* large pool of active organic matter, N “leakage” can be as great as high-input conventional systems.

 The challenge is to ensure adequate PAN available in the crop root zone, and at the same time minimize NO3 leaching and denitrification.

Slide 21 - *… 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. Thus, organic producers must often deal with sharply reduced crop yields during the initial phases of restoring depleted soils, such as during conversion of a field from conventional to organic management. Conventional producers can compensate by increasing soluble fertilizer rates, but this increases the risk of nitrate leaching and denitrification losses in the event of untimely heavy rainfall.

Slide 22 – *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, so that crops are not N limited, yet excess soluble N does not remain in the soil for extended periods of time. If N is released too quickly (for example, after a pre-plant application of the entire season’s recommended N in soluble form), early season rains may leach it out before the crop can utilize it. N released too slowly becomes available only after the crop has entered the maturation phase, resulting in crop N limitation and an increased risk of late season leaching or denitrification losses.

 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 an adequate 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 health is 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.

Slide 23 – *Delivering the 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? We all know that something like this happens in the legume-Rhizobium symbiosis, in which atmospheric elemental nitrogen is “fixed” into plant-available N to the benefit of both symbionts, as shown by the soybean in this illustration. But can other soil organisms help other plants access the large store of organic N by delivering just the right amount to their “doorstep”?

 The good news is that there is strong evidence 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, N, P, K, and other 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 efficiency of N, P, and micronutrient uptake.

 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 described by Louise Jackson and colleagues at UC Santa Cruz as “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 24 – *Nutrient management challenge #3: Phosphorus*

 Many organically-managed soils have elevated soil test P levels, especially when manure or compost are major sources of organic matter and fertility. For example, in its farmer-participatory Soil Health Benchmark Study (<https://pasafarming.org/soil-institute/farm-based-research/soil-health-benchmark-study/>), Pennsylvania Association of Sustainable Agriculture (PASA) documented excellent overall scores on the Cornell Comprehensive Assessment of Soil Health (CASH) on 28 member farms (24 of them organic), but excessive soil P emerged as the one weak point on some of the highest scoring farms.

 Egan, F. 2018. *Too Much of a Good Thing: Compost Brings Phosphorus Challenges to Red Earth Farm*. <https://pasafarming.org/too-much-of-a-good-thing-compost-brings-phosphorus-challenges-to-red-earth-farm/>.

 Egan, F. et al., 2017. Setting and Exceeding Benchmarks for Soil Health on Diversified Organic Vegetable Farms. Presentation at Tri-Societies meeting, Organic Agriculture Soil Health Research Symposium, October 25, 2017.)

 Even when otherwise excellent soil management maintains sufficient micronutrient levels and protects water quality, any soil test P levels in the “very high” (surplus) range can significantly reduce the activity of mycorrhizal fungi, which play vital roles in the soil’s capacity to build stable SOM, and to retain, recycle, and deliver N and other nutrients to plant roots.

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

 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.

 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.

 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.\*

 Intensively managed garden soils with heavy annual compost inputs (> 20 tons/ac-year) look super-rich (photo on right) and can yield well, but long term impacts of inhibited mycorrhizal activity on soil health and crop nutrient use efficiency merit further study.

Slide 25 – *Nutrient management challenge #4: Intensive multi-cropping and high tunnels*

 Small acreage market gardens and high tunnels are often managed intensively, as growers must harvest and market several high value crops per year to stay in business.

 Organic producers often use compost to compensate for the organic matter consumed and nutrients removed during intensive multicropping with routine tillage. This can lead to accumulation of P, and sometimes calcium, zinc or other micronutrients, depending on ingredients used to make the compost.

 Crop rotations that are dominated by salad greens harvested young, and/or root crops in which the entire plant goes to market will return little organic residue to the soil, which can make it more difficult to maintain SOM and soil life without over-reliance on compost.

 When crop rotations are designed to ensure sufficient amounts of residue return and the soil is tilled with care, these intensive rotations can maintain or even build soil health.

Slide 26 – *Goals of organic nutrient management*

 Organic nutrient management must maintain economically viable yields of high quality products, and at the same time protect soil, water, and other resources, and avoid or minimize greenhouse gas emissions. The fundamental step toward these goals is to build healthy soils that will provide for crop nutrition through organic matter and biological activity, thus reducing the need for nutrient inputs from external sources. During transition from conventional production or restoration of depleted soils, additional inputs may be needed to address shortages of specific nutrients, unfavorable pH, or other imbalances indicated by soil test. Once nutrient levels reach optimum (“high”) ranges, nutrient inputs should simply 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 self-sufficiency. For example, correcting a P surplus may enhance mycorrhizal activity and thereby improve cycling of N and other nutrients, including P.

Slide 27 – *Replenishing nutrients: vegetable crops*

 Typical yields, and estimates for N (lower figures), P and K removal based on nutrient concentrations given in Knotts Handbook for Vegetable Growers, 5th ed (D. N. Maynard and G. J. Hochmuth, 2007) cited by Michelle Wander, 2015 in [*https://articles.extension.org/pages/18794/nutrient-budget-basics-for-organic-farming-systems*](https://articles.extension.org/pages/18794/nutrient-budget-basics-for-organic-farming-systems).

 The higher values for N removals are based on nutritional contents (N = protein / 6.25) of edible portions of vegetables, cited in *Nutrition Almanac, 3rd edition* (Lavon J. Dunne, 1990).

 Extension recommendations for N (regardless of soil test) and for P and K at “high” (optimum) soil test P and K levels, from *2018 Mid-Atlantic Commercial Vegetable Production Recommendations*. <https://www.soiltest.vt.edu/Files/handbooks.html> .

 Nutrient replenishment to maintain optimum soil nutrient levels should aim to balance inputs with exports through harvest. NPK recommendations for fertility maintenance seem appropriate for K, high for N (especially head brassicas), and severalfold too high for P.

 Moderate rates of compost and poultry litter fertilizer – two organic amendments commonly used for NPK – can approximate Extension recommendations, but will build up soil P.

Slide 28 – *Grain crops may need little fertilizer on healthy soils*

 The information in this slide is based on a presentation at the January, 2017 Organic Agricultural Research Symposium, and a 2018 NRCS webinar, *Adaptive Nutrient Management*, given May 8, 2018 by Robin ‘Buz’ Kloot, Professor at University of South Carolina. Fertilizer trials were conducted over a five year period with a corn-soy-wheat rotation with high biomass cover crops on an Orangeburg loamy sand soil in South Carolina. The crops showed no yield response to added P or K, and achieved maximum yield at half of the recommended rates of N. Soil organic matter increased by more than a third (from 1.2 to 1.7%), likely because adding winter cover crops maintained living root and biomass production throughout most of the year.

 In the 2018 webinar, Dr. Kloot cited several other 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.

 He noted that most soils, especially southeastern US coastal plain soils, have large subsoil K reserves that cover crop roots readily retrieve. In addition, he cited a University of Illinois review of long term farming trials around the world, showing little or no yield benefit from recommended K applications in a wide range of soils, climates, and farming systems (Khan et al, 2013). This may explain the stable soil test K despite significant net withdrawals through harvest. Soil P was drawn down only slightly, and crop foliar P remained within optimum sufficiency ranges.

 Kloot, Robin. 2017. *Rethinking P and K fertility in coastal plain soils.* Presentation at the 2017 Organic Agriculture Research Symposium, Lexington, KY, January 26, 2017.

 Kloot, Robin. 2018. *Using adaptive nutrient management to answer “how much fertilizer do you actually need?”* NRCS webinar May 8, 2018. Science and Technology Training Library, <http://www.conservationwebinars.net/listArchivedWebinars>.

 Khan, S. A., R. L. Mulvaney, and T. R. Ellsworth. 2013. *The potassium paradox: implications for soil fertility, crop production, and human health.* Renewable Agriculture and Food Systems: doi:10.1017/S1742170513000318. 25 pp.

Slide 30 – *Broccoli – a nitrogen hog?*

 Fertilizer rate trials in California and Virginia utilized a mixture of blood and meat meals (fast release) and feather meal (slow release) to provide different rates of organic N; crop yields increased linearly with rate applied.

 Reference for CA study: 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>.

 Additional studies on five organic farms in Oregon confirmed that organic broccoli yields show a significant linear response to added N (as feather meal) and did not plateau until > 200 lb N/ac. At a market price of $2.50/lb, broccoli yield increases returned several times the cost of the feather meal at all sites. Yet, maximum yields of 7 to 14 tons/ac removed at most 65 – 130 lb N/ac, leaving considerable surplus N subject to leaching to groundwater.

 Douglas Collins and Andy Bary, 2017. *Optimizing Nitrogen Management on Organic and Biologically-Intensive Farms.* Special Symposium on Organic Agriculture Soil Health Research at the TriSocieties meeting, October 25, 2017 in Tampa, FL.

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

Slide 31 – *Tight N cycling in organic tomato*

 The four fields that showed tightly coupled nitrogen cycling with low soluble N yet adequate crop nutrition and high yields were amended primarily with a fairly high C:N compost (20:1) derived from diverse organic materials mixed together, supplemented with a light band application of more concentrated N (blood meal or Chilean sodium nitrate). The soils had also been under organic management with cover crops for a number of years. The investigators documented evidence that the soil life and plant root enzymes interacted to enhance N availability within the rhizosphere without overloading the bulk soil with soluble N.

 UC Santa Cruz 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 32 – *Adjust amendment rates according to soil test P*

 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, see Soil Health and Climate Change Mitigation / Adaptation Guide available at <https://ofrf.org>.

Slide 33 – *Cover crops: a vital tool for organic nutrient management*

 Cover crops play vital, multiple roles in soil-friendly nutrient management. As a key source of organic carbon to feed soil life and maintain soil organic matter, high biomass cover crops enhance the soil’s long term capacity to provide for crop nutrition. For example, most legume and grass cover crops enhance populations of root-symbiotic mycorrhizal fungi, which facilitate plant uptake of moisture, nitrogen, phosphorus, and micronutrients. Buckwheat and crucifer covers do not support mycorrhizal fungi, but do 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 fix more N, and some warm season grasses host N-fixing bacteria in their root zone. When soil soluble N is abundant and susceptible to leaching or denitrification, cover crops switch to “scavenging mode,” absorbing and holding the surplus N for future use, thus protecting water quality and climate.

 When plant-available phosphorus and/or potassium are below optimum for production, 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 (plant-available) K. However, cover crops do not “fix” P and K from thin air the way they do C and N – thus, cover crops will not add unneeded P and K when soil levels are already ample.

Slide 34 – *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, maximizing N fixation where existing soil soluble N levels are low, and maximizing N scavenging where soil N is abundant – in effect, a biological approach to precision farming.

 Some tropical grasses (millets, indigenous land races of corn) support N fixing microbes in their root zones, adding perhaps 10 – 50 lb N/ac when existing soluble N levels are low.

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 all low C:N cover crops, including radish, will release soluble N rapidly when terminated, and can pose environmental risks when tilled in. 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 N2O emissions*. Nature Climate Change 8: 219-223. [www.nature.com/natureclimatechange](http://www.nature.com/natureclimatechange).

 Research at Cornell into organic reduced till / cover crop systems has shown that cabbage yields are inversely related to cover crop C:N ratio, with vetch alone or zone planted vetch/rye giving highest yields (C:N 12 – 30) and other treatments with C:N 40 -80 requiring 60 to 120 lb N/ac for full yield (~14-18 t/ac). Reference: *Reduced Tillage in Organic Systems Field Day Program Handbook,* July 31, 2018 at Cornell University Willsboro Research Farm, Willsboro NY. Page 15. <https://rvpadmin.cce.cornell.edu/uploads/doc_699.pdf>.

Slide 35 – *Cover crop maturity and N 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 their 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 (late vegetative) can reduce biomass and organic matter contributions by half.

 Note that 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 residues with moderate C:N (~20 – 30:1).

Slide 36 – Managing SOM: a balancing act

 In order to meet soil health and crop nutrition objectives, the grower needs to strike a balance between two vital processes mediated by the soil life: building soil organic matter, and mineralizing (metabolizing) organic materials (both fresh residues and SOM) to release nutrients to plants.

 Both of these critical processes can increase simultaneously when an integrated approach to soil health and fertility is implemented: tight, diversified crop rotation with high biomass multispecies cover crops, supplemented with compost or manure used at rates adjusted according to soil test levels of P and other nutrients. Reducing tillage intensity can also contribute to balanced, long term soil fertility.

Slide 37 – *Zone tillage: releasing nutrients where they are needed*

 Ridge tillage and strip tillage promote nutrient mineralization in and near the crop root zone where the nutrients will be efficiently taken up, and SOM stabilization between rows where soil disturbance is minimal. Field trials at several Midwest sites verified that ridge tillage performs these spatially differentiated functions, and can improve overall SOM accrual. The investigators coined the term “soil functional zone management” (SFZM) for this strategy.

 Note that a simple strategy to concentrate fertilizer in the crop “grow zone” is to broadcast organic fertilizers and amendments just *before* building and shaping beds, an operation that moves the amendments onto the bed top, where one or more rows of production crops will be grown. Kat Johnson, manager of Fields Edge Farm in Floyd, VA uses this approach, and informed me of it during a farm visit in summer, 2018.

 Reference for SFZM: 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*. Ag Eco Env 236: 99-107.

 Zone tillage is explored in depth, with lots of practical info in: *Reduced Tillage in Organic Systems Field Day Program Handbook,* July 31, 2018 at Cornell University Willsboro Research Farm, Willsboro NY <https://rvpadmin.cce.cornell.edu/uploads/doc_699.pdf>.

Slide 38 – *Zone planting for nutrient management*

 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.

 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.

Slide 39 – *Summary of best organic nutrient management practices*

 We cannot provide prescriptive organic nutrient management formulas. Regarding organic fertilizers and application rates, consider cost, yield response, net return, and longer term effects on soil health and water quality. The examples covered above show just how complex and site specific the answers can be. However, integrated soil health management is a great starting point.

 In addition to integrating annual cover crops into the rotation wherever they fit, rotating a field into perennial sod for 1-3 years after several years’ intensive cropping is an excellent way to restore SOM, soil life, organic N reserves, nutrient cycling, and overall soil health and fertility.

 Soil tests tell part but not all of the story. A crop nutrient analysis reveals what the crop actually “sees” and can help diagnose the causes of production problems.

 Side by side trials with versus without an organic nutrient source, or low versus higher rates of N, can be especially valuable in fine tuning your fertility program for soil health, cost efficacy and environmental protection.

Slide 40 – *Organic nutrient management research priorities*

 The sharp contrast between responses of different crops to N and other fertility inputs (broccoli vs tomato vs field crops in today’s examples), and between organic tomatoes in fields with different management histories 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 tightly coupled nutrient 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.

 Plant breeding for efficient nutrient utilization from soil organic matter and slow release organic nutrient sources, and especially for effective associations with mycorrhizal fungi, N fixing and N cycling bacteria, and other beneficial soil biota, may lead to major breakthrough toward tighter nutrient cycling for a wide range of crops.

Slide 41 - *Questions*

 The Soil Food Web – the engine of soil fertility and crop nutrition. Diagram from:

Ingham, E. 2000. Soil Biology Primer. USDA Natural Resources Conservation SErvice

<https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/>.