**Breeding New Cultivars for Soil-enhancing Organic Cropping Systems in the Western Region**

*Research-based Practical Guidance for Organic and Transitioning Farmers*

eOrganic Soil Health and Organic Farming Webinar Series

March 27, 2019

Developed and presented by Organic Farming Research Foundation, with funding from USDA Western Region Sustainable Agriculture Research and Education (SARE)

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

Slide 1 – *title slide*.

Slides 2 and 3 – *Research priorities for Western region organic farmers*

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

 Soil health, fertility, and weed management emerged as the top three research priorities. Farmers need new cultivars better suited to organic production systems. For example one farmer “expressed the need for breeding that focuses on good root systems for interacting with healthy organic soil, rather than depleted conventional soil.” (NORA 2016, page 107).

 Plant and animal breeding and genetics for organic systems was one of four core topic areas in an earlier (2007) OFRF National Organic Research Agenda (NORA), the other three being soil health and fertility; organic weed, pest and disease IPM, and organic livestock and poultry production systems. Availability of organic seeds and crop cultivars suited to organic systems remained a high priority concern at the time of the 2016 NORA.

Slide 4 – *Subtitle – The role of crop genetics in soil health – direct and indirect impacts*

Slide 5 – *Can the right cultivars help organic farmers build healthy soils?*

 Crop varieties that are easy to grow organically and have good market appeal will make it easier for additional farmers to transition to organic, and for current organic farmers to stay in business – which means that more producers will adopt soil-enhancing practices and phase-out potentially harmful inputs. Varieties that need less water, fertilizer, or weed and pest control will save the farmer money (further enhancing economic viability of organic) and reduce potentially negative impacts on soil physical, chemical, and biological condition. Other critical traits include resistance to locally prevalent diseases and pests, and resilience to specific stresses such as cool wet soil after planting in the maritime Pacific Northwest or prolonged drought in the semiarid interior.

 Some cultivars contribute more directly to soil conservation and soil health through their rapid canopy closure (protects soil surface), deep, extensive root systems (feeds soil life) and high residue return to the soil.

 ‘Abundant Bloomsdale’ spinach was bred and selected *in* and *for* organically managed fields by several farmer-breeders in the maritime Pacific Northwest working with the Organic Seed Alliance. The result is a cultivar that develops large, savoyed leaves with superior flavor, texture, and market appeal, and that is well adapted to the weather patterns of the Maritime Pacific Northwest, combining cold hardiness and bolt-resistance for consistent performance.

Slide 6 – *Breeding crops to need fewer inputs*

Photo provided by Jared Zystro of Organic Seed Alliance.

Slide 7 – *Breeding crops to feed and build soil*

 Living plants, including both cover and cash crops, are the farmer’s primary soil building tool. Cultivars described as tall, vigorous, having abundant top growth, deep rooted, and/or growing actively over a long season are likely to contribute more organic matter and prevent erosion more effectively than early, compact, short-statured, shallow-rooted cultivars that do not cover the whole field surface.

Slide 8 – *Vigorous, high-biomass cultivars*

 Living plants feed the soil life and build organic matter throughout their growing season (via root exudates + fine root sloughing), and after they die (plant residues). The more photosynthetic production per acre per year, the greater is the potential to build soil health. Vigorous top growth and early canopy closure also protect the soil surface from raindrop impact and direct sun, thereby reducing surface crusting and erosion.

 The tradeoff between production for market and residue return to the soil is reflected in the “harvest index,” the ratio of the harvested portion to total plant biomass. Historically, corn, soybean, cereal grains, and some other crops have been bred and selected for shorter stature and higher harvest index to facilitate mechanical harvest and reduce what was then thought of as “wasteful” partitioning of plant resources into non-harvested parts.

 With increased understanding of the importance of maintaining soil health, some plant breeders now place more value on what is returned to the soil as well as what goes to market. While narrow and intensive selection for one can compromise the other, selection for vigorous above- and below-ground growth generally enhances both yield potential and soil benefits.

Slide 9 – *Deep, extensive root system*

 Root residues are converted into soil organic matter more efficiently (~35%) than aboveground plant residues (15-20%). Deep rooted crop varieties can break through subsoil hardpan, bring soil life and organic matter deeper into profile, improve drainage, and also retrieve deep moisture and nutrients, thereby reducing input needs.

 Weil, R. R, and N. C. Brady. 2017. The Nature and Properties of Soils, 15th Edition.

Slide 10 – *Root depth, mass, and architecture as heritable traits*

 Dense, fibrous root systems, such as those of ryegrass and cereal grains, provide a rich supply of root exudates to support the growth of soil microbes, which in turn promote soil aggregation and improve tilth. Well-developed root systems also build stable SOM and absorb excess soluble N and other nutrients, thereby enhancing soil health and protecting water quality.

Many annual crop plant species show a genetic potential to send roots as deep as 6 feet or more, yet most modern cultivars root only to about 3 feet. Breeding and selection for deeper, more extensive, and denser root systems has been suggested as a strategy to sequester carbon and thereby help combat climate change. In addition, deep roots facilitate crop nutrient and water use efficiency, reducing needs for these inputs; protect water quality (deep rooted cover crops can “scrub” most of the excess nitrate-N to depths of 6 to 8 feet); break subsurface hardpan and enhance drainage and tilth; and “feed” soil life to a considerable depth in the soil profile.

 Kell, D.B. 2011. *Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration*. Ann. Bot. 108(3): 407–418.

Slide 11 – *Effective teamwork with soil microbes*

 The capacity of plants to interact effectively with mycorrhizal fungi and other desirable organisms is substantially modulated by plant genetics, and significant heritable variation among cultivars of a specific crop has been documented for many crops.

Slide 12 – *Subtitle: The role of crop genetics in soil health: research examples*

Slide 13 – *Nitrogen-efficient field corn*

 Dr. Walter Goldstein and colleagues at Mandaamin Institute in Elkhorn, WI collected germplasm from Mexican and South American land races that had been grown for centuries without modern agricultural fertilizers and other inputs, and crossed them into standard Corn Belt hybrids and inbred breeding lines. From these crosses, they have developed new advanced breeding lines with enhanced root systems (larger, better association with soil microbiota that fix N and otherwise assist crop nutrient acquisition), yields equivalent to standard hybrids, higher grain protein quality (methionine content, important for organic poultry feed), and much better resilience to drought, low soil N, and other stresses.

 Seed is now available to growers and scientists through cooperative licensing agreements.

 Evidence from breeding research and literature review by Dr. Goldstein and colleagues at Mandaamin Institute suggest that breeding and selecting modern corn hybrids *in* and *for* conventional systems with high N inputs may have modified the relationships between corn roots and soil microbiome so that *Fusarium* fungi proliferate and carry over to future generations via seed. While the *Fusarium* benefits the crop in some ways, including enhancing resistance to some pests and diseases, it also inhibits the establishment of diazotrophic (N fixing) bacteria in and near corn roots, and increases plant susceptibility to N deficiency.

 Both plant genetics and management system (organic versus soluble N sources) have major impacts on the endophyte (within root tissue), rhizoplane (on root surface) and rhizosphere (soil in the immediate vicinity of roots) microbiota, and this in turn impacts ability to fix N and utilize N from organic materials, as well as corn response to applied N.

 Even a few years’ seed increase under organic versus conventional management can improve the resilience of corn breeding lines to low soil soluble N.

 Seeds of the new N-efficient corn cultivars, many showing superior protein levels and quality (methionine content), are now available through Nokomis Gold Seed Company.

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

 Goldstein, W. 2018. *High Methionine, N Efficient Field Corn from the Mandarin Institute/ Nokomis Gold Seed Co.* Proceedings of the 9th Organic Seed Growers Conference, Feb 14-17, 2018, Corvallis OR, pp 25-26. <https://seedalliance.org/all-publications/>.

 Goldstein, W. 2015. *Breeding corn for organic farmers with improved N efficiency/N fixation, and protein quality*. Proceedings of the Organic Agriculture Research Symposium, LaCrosse, WI February 25-26, 2015. <http://eorganic.info/node/12972>.

Slide 14 – *Growing tomatoes on less water*

 The potential to select tomato and many other vegetable crops for drought resilience is suggested by the information in some seed catalogues noting particular varieties as “drought tolerant” or needing less watering.

 Tomato is a deep rooted crop (to 4 ft) that is considered drought-tolerant because it can access subsoil moisture reserves. Growers sometimes limit irrigation on tomatoes to improve flavor, dry matter content, and nutrient density, as well as reduce irrigation costs. In an OFRF funded project, Dr. Amelie Gaudin at University of California at Davis and farmer collaborator Scott Park of Park Farm Organics found that, on a healthy, organically managed soil, irrigation can be stopped two weeks early (45 vs 30 days before end of harvest) without yield loss, saving some 6 inches of applied water. More information at <https://ofrf.org/research/database>, and video at <https://www.youtube.com/watch?v=yapM4_SUu6I>.

 In the “dry farming” method now gaining popularity in California, irrigation is stopped after early crop establishment (for coastal areas with mild summers) or at flowering (hot summer), or limited to “deficit” rates during fruiting in drier areas. However, tomato varieties differ greatly in drought hardiness; thus cultivar selection is an important consideration in limited-moisture tomato production.

 The slide photo shows a tomato variety trial conducted under dry farming conditions by the UC Davis Student Collaborative Organic Plant Breeding Education (SCOPE) project.

 In addition to lowering production costs, reduced irrigation inputs can support soil health by limiting nutrient leaching and minimizing periods of ponding, runoff, and compaction.

 Lynn Byczynski. 2010. New strategies for great tasting tomatoes. Growing for Market, April 2010. <https://www.growingformarket.com/articles/Improve-tomato-flavor>.

 EcoFarm, 2015. Dry farming tomatoes – fresh dirt from the farming mentor. Ecological Farming Association, <https://eco-farm.org/blog/dry-farming-tomatoes-fresh-dirt-farming-mentor>.

Slide 15 – *Breeding drought-resilient grains*

 Major grain crops demonstrate extensive genetic variability and selection potential for drought tolerance.

 Dr. Kevin Murphy of Washington State University has received funding through the USDA Organic Research and Extension Initiative (OREI) and other grant funding to research, breed, and develop cultivars of millets, barley, spelt, quinoa, buckwheat, and other specialty grains to help vegetable producers add higher-residue, soil building crops to the rotation without foregoing as much income as cover crops or feed grains may entail. Working with farmers in participatory breeding endeavors in the Pacific Northwest and overseas, his program selects crops for drought and heat resilience and overall performance in ecological farming systems, as well as yield, flavor, and nutritional value.

 Breeding programs of international crop improvement agencies such as CIMMYT (wheat and maize), IRRI (rice), and ICARDA (dryland systems) have included drought tolerance as a breeding and selection objective. The importance of drought tolerance for all agricultural systems will increase with climate change.

 Zystro, J., and E. Silva. 2016. Breeding for resiliency in the face of climate chaos. Proceedings of the 8th Organic Seed Growers Conference, Corvallis, OR, Feb 4-6, 2016, pp 160-164.

Slide 16 – *Carrot improvement for organic agriculture (CIOA)*

 The Carrot Improvement for Organic Agriculture (CIOA), <http://eorganic.info/group/7645>, takes a holistic and farmer-participatory approach to develop new carrot cultivars for organic production systems, with attention to multiple traits of vital importance to growers. With renewed funding from OREI, CIOA is advancing breeding lines with resistance to two major root knot nematodes; and other lines that combine flavor, enhanced carotene content, and resistance to two major diseases, leaf blight (Alternaria dauci) and cavity spot (*Pythium* spp).

 Simon, Pl, M. Colley, L. MeKenzie, J. Zystro, C.McCluskey, L. Hoagland, P. Roberts, J. Colquhoun, L. du Toit, J. Nunez, E. Silva, and T. Waters. 2016a. The CIOA (Carrot Improvement for Organic Agriculture) Project: *New Sources of Nematode Resistance and Evidence that Location, Cropping System, and Genetic Background Influence Carrot Performance*. Pp. 26-31 in Proceedings of the 8th Organic Seed Growers Conference February 4 - 6, 2016, Corvallis, OR. <http://seedalliance.org/publications#publication_category_title_13>.

 Simon, P. W., M. Colley, J. Zystro, P. Roberts, L. Hoagland, L. and C. McCluskey. 2016b. Carrot Improvement for Organic Agriculture Webinar. <http://articles.extension.org/pages/72577/carrot-improvement-for-organic-agriculture-webinar>.

 COIA website <http://eorganic.info/group/7645>.

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

 Simon, P. W. 2017. CIOA-2 Carrot improvement for organic agriculture with added grower and consumer value. Proposal and progress report on OREI project 2016-04393. CRIS Abstracts.\*

Slide 17 – *Weed-competitive carrots*

 The CIOA team is making progress toward combining the weed competitive traits of early emergence, seedling vigor, large tops, and early canopy closure with good resistance to *Alternaria dauci,* the causal pathogen inleaf blight, one of the leading carrot diseases that can cause substantial yield losses. In addition, trial results reported at the 8th Organic Seed Growers Conference (2016) showed a generally positive correlation between top size, root weight, and flavor.

 Vigorous top growth and early canopy closure not only reduce the number and intensity of cultivations, but provide better protection of the soil surface from raindrop impact and direct sun, all of which are beneficial to soil health.

Slide 18 – *Genetics of plant-soil-microbe partnerships in carrots*

 A growing body of research findings indicates that plant genetic factors play a significant role in the efficacy of beneficial plant root – soil microbe interactions, and in the species composition of endophytic (within plant tissue) and rhizosphere (root zone) microbiomes. Mycorrhizal fungi are especially important plant root symbionts that grow within plant root tissue and out into the soil, effectively doubling or tripling the plant’s root system. Dr. Erin Silva, a collaborator on the CIOA, received a 2016 grant from Organic Farming Research Foundation, as well as other funding, to explore the plant genetic component in the capacity of carrot cultivars to enter into effective symbiosis with mycorrhizal fungi. Results thus far indicate that the efficacy of an applied mycorrhizal inoculant can be influenced by crop cultivar as well as climate, weather, and soil conditions (Erin Silva, 2019, personal communication).

 The CIOA team has also collected and isolated a diversity of endophytic microbes from field grown carrots that can enhance crop nutrition, growth and vigor through multiple mechanisms: solubilizing soil P, fixing N, producing siderophores (iron-solubilizing chelating compounds), producing the plant hormone auxin, and suppressing the carrot leaf blight pathogen *Alternaria dauci*. They documented crop genotypic variation in crop response to endophytes, pointing to an opportunity for varietal selection to optimize plant-root-microbe partnerships (Abdelrazek, 2018). While bacteria of the genus *Pseduomonas* showed the greatest in vitro activity against *A. dauci* and greatest carrot growth stimulation in greenhouse trials, Abdelrazek and Hoagland (2017) recommend further research to better understand the entire endophyte community and its interaction with the plant before attempting to develop practical applications,.

 Other soil microbiologists have also recommended breeding and selecting a range of mycorrhizal host crops (grains, legumes, etc) for enhanced capacity to associate with these important soil fungi.

 Silva, E. 2016. OFRF project summary. <https://ofrf.org/research/grants/creating-climate-resilient-organic-systems-enhancing-arbuscular-mycorrhizal-fungi>.

 Abdelrazek, S., and L. A. Hoagland. 2017. Potential functional role of carrot endophyte communities. Tri-Societies Meetings, Tampa, FL, October, 2017.

 Abdelrazek, S. 2018 *Carrot Endophytes: Diversity, Ecology and Function.* Abstract, PhD thesis, Purdue University.

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

Slide 19 – *Tomato organic management and improvement (TOMI)*

 The Tomato Organic Management and Improvement (TOMI) team aims to develop an integrated approach to disease management and optimum nutrient uptake, including plant breeding for stable (horizontal, multi-mechanism) resistance to a half dozen leading diseases of tomato, and induced systemic resistance (ISR), in which beneficial micro-organisms or other stimuli cause the plant to mount defenses against pathogens.

 For more information on the TOMI project, visit the web page of Dr. Lori Hoagland at Purdue University. <https://ag.purdue.edu/hla/Pages/Profile.aspx?strAlias=lhoaglan&intDirDeptID=16>.

Slide 20 – *Induced systemic resistance (ISR)*

 A tomato land race (‘Colombia’) showed a strong response to beneficial *Trichoderman harzianum* fungi, with “dramatic improvements in early growth, transplant establishment, and induced resistance to both pathogens,” while a modern disease-resistance hybrid (‘Iron Lady’) showed a much weaker response (Hoagland, 2018). Genetic traits appear to regulate the crop’s capacity to respond to *T. harzianum* and other beneficial soil organisms with a systemic and broad spectrum disease-resistance response. In a study of 30 tomato genotypes representing a “domestication gradient,” most showed positive growth responses to *T. harzianum*, but the wild strains and land races showed the greatest ISR response (protection against late blight *Phytophthora infestans* and gray mold *Botrytis cinerea*), and “early modern” (heirloom) cultivars showing the least ISR response (Amit Jaiswal and Lori Hoagland, personal communication, 2019). Some “modern breeding lines” with which the TOMI project is working show signs of recovering some of the ISR response.

 This represents a new advance in the development of disease-resistant crop cultivars. Many of the “disease resistant” varieties of the 20th Century possessed a single gene that conferred immunity to the target pathogen (“vertical” resistance). However, many pathogens, especially the “water molds” such as the downy mildew pathogens and *Phytophthora* spp. (late blight of tomato and potato, and virulent root rot diseases of many crops) rapidly evolve the ability to overcome single-gene resistance, which results in cultivars rated as resistant only to certain races of disease X. “Horizontal” disease resistance, based on multiple genes that improve tolerance to pathogens through multiple mechanisms, is often not as “absolute” (disease symptoms may appear but do not become as severe or yield-limiting), but is more stable, in that it is harder for pathogens to evolve renewed virulence against these cultivars.

 The TOMI team has already developed advanced tomato breeding lines that combine good flavor and horizontal resistance to several major tomato diseases. Transferring the genes for robust ISR response from land races into new cultivars would add yet another, potent mechanism for resilience to multiple pathogens.

 Lori A. Hoagland, 2018. Proposal and progress report for OREI project 2014-05405, *Practical approach to controlling foliar pathogens in organic tomato production through participatory breeding and integrated pest management*. CRIS Abstracts.\*

 Egel, D., L. A. Hoagland, and A. Jaiswal. 2018. *Organic tomato foliar pathogen IPM webinar,* <https://articles.extension.org/pages/25242/webinars-by-eorganic>.

 Zubieta, L. and L. A. Hoagland. 2017. *Effect of Domestication on Plant Biomass and Induced Systemic Resistance in Tomato (Solanum lycopersicum L.).*

Poster Number 1209, Tri-Societies Meetings, Tampa, FL, Oct 24, 2017.

Slide 21 – *Tightly coupled N cycling in organic tomato in California*

 In a study of thirteen organic tomato fields in central California, UC Santa Cruz researchers identified three distinct patterns: N-deficient, N-saturated, and tightly coupled N cycling in the root zone. Soil health and organic inputs played a major role, in that diverse inputs with a moderate C:N ratio maintained higher SOM, greater microbial activity, and tighter nutrient cycling than dependence on concentrated nutrient sources like poultry litter and guano. However, the researchers identified at least one plant root enzyme involved in N cycling, which seemed to be up-regulated by the healthy soil conditions that promote tightly coupled N cycling.

 In her 2013 final report, project PI Louise Jackson states: “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 22 – *Breeding cover crops for soil health*

 Cover crops are grown primarily for soil health and fertility, and other conservation goals. In recent years, both farmers and plant breeders have become more interested in selecting cover crop cultivars to optimize their services to the agricultural ecosystem. A substantial body of research has documented significant heritability (genetic variability among cultivars and breeding lines) for several key cover crop traits that directly impact soil health, nutrient cycling, and adaptability to region, crop rotation, and seasonal niche.

Slide 23 – *Hardiness and maturity date*

 Fava bean is a cool season cover crop, normally hardy to about 20°F. Erik Landry and colleagues at Washington State U identified four winter-hardy lines of small-seeded fava bean (bell bean) and further improved their hardiness through selection over four years. The improved lines, with 32 – 43% survival to - 12°F, were registered in 2015 and made available to plant breeders for further development into cover crop or pulse (edible bean) crops.

 In Minnesota, local land races of hairy vetch (saved by MN farmers) overwintered better (42-58% survival) and gave higher biomass and N than commercial seed produced in warmer parts of the North-Central region (2-12%) (Sheaffer et al., 2007).

 Organic grain farmers in Tennessee grow early-maturing ‘Purple Bounty’ hairy vetch and ‘Abruzzi’ rye, allowing timely roll-crimping for no-till corn and soybean planting. They have also observed variation among vetch lines in no-till termination, and achieve 100% kill in ‘Purple Bounty’ roll-crimped at full bloom.

 Erik J. Landry, Jolene E. Lafferty, Clarice J. Coyne, William L. Pan, and Jinguo Hu. 2015. Registration of Four Winter-Hardy Faba Bean Germplasm Lines for Use in Winter Pulse and Cover Crop Development. Journal of Plant Registrations 9:367–370 (2015).

doi:10.3198/jpr2014.12.0087crg

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

 Information on Purple Bounty vetch and Abruzzi rye was shared in a presentation, *Growing Organic Grains to Sell*, given by Alfred and Carney Farris and Holden and Rebekah Thompson of Windy Acres Farm in Tennessee (<http://windyacrestn.com/>) on January, 28, 2017, at the Southern SAWG Conference in Lexington, Kentucky.

Slide 24 – *Breeding hairy vetch, Austrian winter pea, and crimson clover for organic systems*

 Dr. Steve Mirsky and colleagues at USDA Agricultural Research Service in Beltsville, MD has initiated a major plant breeding endeavor for three leading winter annual legume cover crops. The team is working with farmers and other breeders to evaluate and select breeding lines, and develop new cultivars adapted to each of the four major USDA regions in the US.

 Breeding priorities for the three winter legume covers are based on a farmer survey with 504 respondents, of which approximately 90% cited N fixation, and 60-65% cited each of the traits of winter hardiness, biomass production, early vigor, and weed suppression. Additional breeding objectives include early maturity and disease resistance (35-40% of farmers); absence of hard seed (risk of delayed emergence as a weed in subsequent cash crops, cited by 20% of farmers); and ease of no-till mechanical termination (hairy vetch).

 The project team aims to extend the endeavor beyond the life of OREI funding through the regional Cover Crop Councils (helped establish the Northeast CCC), and by establishing strong farmer-researcher networks. For example, the team has engaged Practical Farmers of Iowa (PFI) in on-farm breeding and cultivar evaluation trials.

 Mirsky, Steven B. 2018. Project proposal and progress report for OREI funded project 2015-07406, *Creating the Cover Crops that Organic Farmers Need: Delivering regionally adapted varieties across America*, and proposal for OREI project 2018-0282, *Selection to Distribution: delivering regionally adapted cover crop varieties to organic farmers.* CRIS Abstracts.\*

 Ackroyd, V. L. Kissing-Kucek, and S. B. Mirsky (USDA ARS Beltsville, and Cornell U). *Northeast Cover Crop Efforts*. Powerpoint presentation that includes description of the cover crop breeding effort. <http://mccc.msu.edu/wp-content/uploads/2016/11/MCCC2016_Northeast-Cover-Crop-Efforts.pdf>.

Slide 25 – *Subtitle – challenges in finding the best crop cultivars*

Slide 26 – *Challenge #1: Modern varieties are not designed for organic systems*

 Organic growers must often compensate for the genetic limitations of today’s cultivars (poor competitiveness toward weeds, limited ability to utilize N from organic sources) with increased cultivation and heavier applications of organic fertilizers – practices that increase production costs and can compromise soil health and water quality. Some recent organic nutrient management studies have illustrated this challenge in the case of broccoli, modern cultivars of which appear to lack the capacity to utilize either soil-derived or applied organic N efficiently. Organic broccoli can be profitable, but the economic “sweet spot” occurs at 200 – 220 lb N/ac from organic sources, which is sufficient to lead to serious N leaching and denitrification into the greenhouse gas nitrous oxide.

 Hultengren, R., M. Glos, and M. Mazourek, 2016. *Breeding Research and Education Needs Assessment for Organic Vegetable Growers in the Northeast*. Organic Seed Alliance, <http://www.seedalliance.org/>

 Collins, D. P. and A. Bary. 2017. *Optimizing nitrogen management on organic and biologically intensive farms.* Proceedings of the Special Symposium on Organic Agriculture Soil Health Research at the Tri-Societies Annual Meeting, Tampa, FL, October 22-25, 2017. [http://articles.extension.org/pages/74555/live-broadcast:-organic-soil-health-research-special-session-at-the-tri-societies-conference](http://articles.extension.org/pages/74555/live-broadcast%3A-organic-soil-health-research-special-session-at-the-tri-societies-conference).

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

Slide 27 – *Have modern crop cultivars forgotten how to “talk” with soil life”*

 A growing body of research findings, including but not limited to those of the TOMI and CIOA projects cited above, indicates that plant genetic factors play a major role in the efficacy of beneficial plant root – soil microbe interactions, and in the species composition of endophytic (within plant tissue) and rhizosphere (root zone) microbiomes. Evidence is accumulating that 20th century breeding and selection for high input conventional production systems may have attenuated crop genetic capacity for such interactions in field corn, tomato (Abdelrazek and Hoagland, 2017; Goldstein, 2016, cited above), and other crops. Reversing this trend through selection in and for organic production systems constitutes a key plant breeding frontier – and may help close the 20% “yield gap” between organic and conventional production averages.

Slide 28 – *Challenge #2: cultivar choices are limited and not adapted to locale*

 Because the private for-profit plant breeding and seed industries do not effectively serve the organic sector, organic farmers depend more on public plant breeders in universities, USDA, and non-profit non-governmental organizations to develop and produce the crop seeds they need.

Slide 29 – *Farmer frustration with organic seed*

 Jerkins, D., and J. Ory. 2016. *2016 National Organic Research Agenda*. <https://ofrf.org>.

Slide 30 – *Challenge #3: public plant breeders are an endangered species*

Slides 31 and 32 – *Challenge #4: Intellectual property rights and farmers’ rights*

 The goal of the Open Source Seed Initiative is to build a genetic commons of germplasm that can never be privatized through patents or other Intellectual Property Rights (IPR) restrictions. The challenge for the open source approach is how to fund ongoing plant breeding endeavors, and to:

* Make seed available to producers at reasonable cost and without intellectual property rights restrictions against on farm seed saving.
* Provide a viable living for the scientists and plant breeders who develop and release public cultivars, and
* Provide sustained funding for robust plant breeding programs over the long run.

 Utility patents, most commonly placed on genetically engineered (GMO) crop seed developed by private for-profit businesses (usually large corporations like Syngentis or Bayer-Monsanto) prohibit farmers from saving seeds even for their own use, and severely restricts access to germplasm by plant breeders within the public realm or otherwise outside the firm that holds the patent. Seed costs are often much higher as well, since the development of a GMO cultivar from concept to market costs well over $100 million and the patent holder must recover the costs.

 Other models that aim to preserve some “seed freedom” on the farm while financially sustaining plant breeders and breeding programs include the PVP, seed licensing agreements between university or private developers of cultivars and end users, and a royalty surcharge on seed purchase price to fund ongoing breeding endeavors.

Slide 33 – *Subtitle slide – meeting the challenges; working together to develop seeds for healthy soils and healthy organic farm profits.*

Slide 34 – *Farmer-participatory plant breeding (PPB)*

 Farmer-participatory plant breeding (PPB), an approach taken by Organic Seed Alliance and other non-profit oroganizations, several OREI-funded plant breeding endeavors, and a number of small independent seed companies, is a highly effective and cost efficient approach to developing the new cultivars that organic growers need to meet their soil health, production, and marketing goals. By engaging producers in all stages of the process including on-farm trials under organic management, PPB aligns breeding goals and methods to farmer needs and promotes adoption and utilization of new releases, as well as yielding cultivars well adapted to organic production systems and regional soils and climates.

 Collaborative PPB encourages a systems approach to cultivar development, addressing multiple objectives at once (e.g. flavor, disease resistance, and cold tolerance for corn in cold-temperate climate), and avoiding the pitfall of focusing on single traits. For example, selecting narrowly for rooting depth or resistance to a specific pathogen may not yield the range of cultivar adaptation required. Tall growth habit and rapid canopy closure can enhance weed suppressiveness, yet may lead to more lodging or a more favorable environment for fungal pathogens.

 Van Bueren, E. L. 2016. *Enhancing Resilience Through Plant Breeding Requires an Integrated and Interdisciplinary Approach*. Pp 133-135 in in Proceedings of the 8th Organic Seed Growers Conference February 4 - 6, 2016, Corvallis, OR. <http://seedalliance.org/publications#publication_category_title_13>.

Slide 35 – *Northern Organic Vegetable Improvement Collaborative (NOVIC)*

Slide 36 – *Student Collaborative Organic Plant Breeding Education (SCOPE)*

 SCOPE has sought, and will continue to seek, organic farmer input on plant breeding objectives and priorities, as well as conducting on-farm breeding, selection, and cultivar development. Farmers interested in participating in the SCOPE breeding efforts, testing SCOPE breeding lines, or providing input on future priorities are invited to contact Jared Zystro of Organic Seed Alliance, jared@seedalliance.org.

Slide 37 – *PPB Researcher enthusiasm and practical challenges*

 The strong enthusiasm on the part of researchers about working with farmers in plant breeding and cultivar evaluation foretells a great potential and strong future for farmer-participatory plant breeding (PPB). This approach does face a few challenges. In addition to learning the basic skills of field evaluation of cultivars and record keeping, farmer-breeders must learn how to perform controlled crosses, select successive generations simultaneously for several priority traits (e.g., drought resilience, disease resistances, competitiveness toward weeds, flavor, and keeping quality), and manage seed production, harvest, cleaning, and storage to maintain quality and vigor.

 Many farmers are committed to sharing their new cultivars and breeding lines with no or minimal intellectual property rights restrictions. Yet they must make a sufficient income from their breeding efforts to make it financially viable to provide this valuable service to the wider farming community.

 In addition to the plant breeding effort itself, which takes 4 to 10 years from idea to farmer-ready cultivar, the additional tasks of testing the cultivar in different environments, producing seed in commercial quantities, developing relationships with seed vendors, and marketing the new release can take an additional 2 to 4 years (Micaela Colley, Organic Seed Alliance, personal communication, Oct 2018).

 Hubbard, C. and J. Zystro. 2016. *State of Organic Seed, 2016*. Organic Seed Alliance, 112 pp. <https://stateoforganicseed.org/>.

Slide 38 – *Subtitle - Tips for find the seed you need*

Slide 39 – *Making the best use of what is available*

 Choose cultivars that are adapted to the soil conditions, pest and disease pressures, and other stresses likely in your region, be they drought, heat, cold, untimely frosts, etc. Note that seed of a given cultivar that is grown organically within your region may perform better than seed of the same cultivar grown with conventional inputs or grown organically in a different region, climate, and soil type.

 A good place to start is catalogues of seed companies in your area that offer organic and regionally produced seeds, including cultivars that have been developed and/or tested by regional farmers or farmer networks. Do on-farm comparisons of several varieties for a few successive seasons to identify consistent performers.

Slide 40 – *Sourcing and choosing organic seed*

 Some seed vendors provide excellent information on cultivar traits including maturity dates, habit of growth, soil preferences, disease resistance, and stress tolerance, as well as key market traits.

 Blue River Organic seed, [www.blueriverseed.com](http://www.blueriverseed.com), provides seeds for corn, soybean, cereal grains, and forages in 25 states. Cultivars are bred and selected for organic systems, and each cultivar description includes ratings (1-5 scale) for emergence and early vigor, growth habit and root strength, adaptation to different soil conditions including high and lower fertility, and tolerance to heat, drought, specific diseases, and other stresses.

Slide 41 – *Get involved: breed and grow better seeds for organic farms*

 Multiple opportunities exist to become involved in seed production, cultivar trialing, and on-farm plant breeding. Networking with other farmers, breeders, and scientists can enhance the educational value of the experience as well as practical outcomes. See the OFRF Soil Health Guide on Plant Breeding and Genetics for links to these resources and networks.

Slides 42 and 43 – *Resources for participatory plant breeding and organic seed production*

 In addition to extensive on-line written information resources on organic seed production, on-farm variety trials, and plant breeding techniques, OSA offers intensive workshops on these topics at various locations around the nation, and partners with several OREI funded breeding endeavors including Northern Organic Vegetable Improvement Collaborative.

 Micaela Colley of OSA states: “Regional networks of seed stewards, like the network of farmers that delivered ‘Abundant Bloomsdale,’ are protecting genetic diversity in our food crops while expanding choice in the organic seed marketplace. And because ‘Abundant Bloomsdale’ is open-pollinated, growers are encouraged to save and select seed from their harvests to adapt the variety to their own local growing conditions and market needs. This is especially important as regional climates continue to shift.”

 For more information, see <https://seedalliance.org/2015/osas-abundant-bloomsdale-spinach-hits-marketplace/>.

Slide 44 – *Seed companies with PPB programs*

 This list is not exhaustive; other seed companies within the Western region and across the US have plant breeding or variety evaluation programs with farmer participation.

Slide 45 – *Subtitle – Research development in public plant breeding for organic*

Slides 46 and 47 – *USDA funding for plant breeding for organic systems*

 The OREI has provided a vital source of funding for public, classical (non-GMO) plant breeding endeavors, especially in vegetable crops, with emphasis on farmer-identified needs and priorities. OREI continues to support several farmer-breeder networks, including NOVIC, CIOA, TOMI, and the cover crop breeding endeavor. Renewed funding for these networks supports long term commitment to public cultivar development, release, and commercialization.

Slide 48 – *Looking into the near future.*

 TOMI has developed breeding lines via field selection and marker assisted breeding with resistance to Late Blight, Early Blight, Septoria Leaf Spot, Bacterial Speck and Spot, Fusarium and Verticillium wilts. Seed increase and initial release anticipated in the next few years.

Regarding CIOA work, Micaela Colley of OSA notes: “Phil Simon's program, UW Madison, and Phil Roberts, UC Davis, also released carrot breeding material with dual resistance to the two primary nematodes that affect carrots, *Meloidogyne incognita,* and *M. javonica*. While this release was breeding stocks, not a finished cultivar, it is important to note that release of important breeding materials also contributes to the seed industry's ability to breed improved cultivars for organic systems.”

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

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

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