Crop Breeding and Variety Selection for Soil Health

Research-based Practical Guidance for Organic and Transitioning Farmers

eOrganic Soil Health and Organic Farming Webinar Series
November 14, 2018
Developed and presented by Organic Farming Research Foundation, with funding from the Clarence Heller Foundation

Slide 1 – *Title slide*

Slide 2 – *2016 National Organic Research Agenda (OFRF)*

A total of 1,403 respondents representing all four USDA regions (Northeast, North Central, South, and West) participated in OFRF's 2015 survey to identify top research priorities. In addition, 21 listening sessions were held in conjunction with conferences across the US; during which farmers expressed their need for crop cultivars better suited to organic farming systems. For example:

> *One farmer stated that wheat varieties currently are "short wheat, short root systems, lower protein and mineral content, higher nitrogen needs, are really not what we need." The farmer expressed the need for breeding that focuses on good root systems for interacting with healthy organic soil.* (NORA 2016, page 107).

Several farmers expressed strong interest in participatory plant breeding, with on-farm variety evaluation, breeding, and selection. The need for more public plant breeders, especially those that prioritize cultivar development for organic and sustainable systems, also emerged through the survey and listening sessions.

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 microbiology, health and fertility; systems approach to weed, pest and disease management, 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 3 – *Subheading – The role of crop genetics in soil health*

Slide 4 – *Can the right cultivars help farms build healthy soils?*

Crop varieties that are easy to grow organically will make it easier for additional farmers to transition to organic, and for current organic farmers to continue – 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. Some cultivars can contribute more directly to soil conservation and soil health.

Example: 'Who Gets Kissed' sweet corn was bred and selected *in* and *for* organically managed fields in a cold-temperate climate with a short growing season. Developed collaboratively in a farmer-participatory breeding program by Dr. Bill Tracy and Dr. Adrienne Shelton of University of Wisconsin, Dr. John Navazio of Johnny's Selected Seeds, Jared Zystro of the Organic Seed Alliance, and Wisconsin farmer Martin Diffley, 'Who Gets Kissed' is an open pollinated cultivar that combines excellent emergence from cool soil, resistance to common rust and corn smut, early maturity, and superior flavor and sweetness compared to other early sweet corns.

Slide 5 – *Easy to grow organically*

'South Anna' butternut squash was developed by organic farmer, plant breeder, and seed grower Edmund Frost of Common Wealth Seed Growers in Louisa, VA, from a cross between 'Waltham' butternut (standard variety, good yield and flavor, but susceptible to downy mildew) and 'Seminole' pumpkin (grown by Native Americans since before Columbus, tremendous vigor, disease resistance, long shelf life).

Slide 6 – *Need fewer inputs*

The seed fir this 'Tennessee Red Cob Dent' corn was obtained at a growers seed exchange at a sustainable agriculture conference in the southeastern US in 2015. It was clearly well adapted to the Floyd, VA climate and soil conditions (Appalachian region, highly weathered loamy soil). Another variety, similarly acquired at a regional conference in 2017, 'Bloody Butcher' performed even better, with superb seedling vigor (6 in height and 8 in long root at 12 days after planting), vigorous growth, and good yield on medium-fertility soil with light applications of compost and feather meal. This cultivar produces deep red kernels (market appeal!) and some of the best tasting flour corn available anywhere. Note that in other environments (e.g., Wisconsin with short growing season, or New Mexico with limited rainfall), these cultivars might not perform as well – so shop locally!

Slide 7 – *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 or otherwise assist the crop in 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.

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 8 – *Restoring soil-enhancing traits in corn*

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 hybrids and breeding lines, 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/.

Slide 9 – *Growing tomatoes on less water*

Tomato is a deep rooted crop (to 4 ft) that is considered drought-resilient 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 save on irrigation costs. In the "dry farming" method now popular 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.

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.

Reduced irrigation inputs can support soil health by limiting nutrient leaching and minimizing periods of ponding, waterlogging, and compaction.

Slide 10 – *Heritable drought resilience*

Southern Exposure Seed Exchange, based in central Virginia, https://www.southernexposure.com emphasizes organically or ecologically produced heirloom vegetable, herb, and grain seeds adapted to the mid-Atlantic and southeastern US, including tomato, peanut, cucumber, lima, okra, and other crop varieties noted in the catalogue for their heat and drought tolerance.

The extensive genetic variability, and hence selection potential, for drought tolerance in a wide range of staple grains is evidenced by the breeding programs of international crop improvement agencies such as CIMMYT (wheat and maize), IRRI (rice), and ICARDA (dryland systems). The importance of drought tolerance as a breeding objective 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 11 – *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.

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. 2016. *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. 2016. *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 12 – *Weed-competitive carrots*

The 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 in leaf 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.

Slide 13 – *Protect and build soil, feed soil life*

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 limit erosion more effectively than early, compact, short-statured cultivars that do not cover the whole field surface.

Slide 14 – *Vigorous, high-biomass crops*

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 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 are beginning to place value on what is returned to the soil as well as what goes to market.

Slide 15 – *Deep, extensive root systems*

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 irrigation and fertility input needs. Some deep rooted crops such as pearl millet, sorghum, tillage radish, forage turnip, and chicory can "mop up" surplus soil nitrate throughout the top 4 to 8 feet of the soil profile.

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

Marshall, M.W., P. Williams, A. Mirzakhani Nafchi, J. M. Maja, J. Payero, J. Mueller, and A. Khalilian. 2016. *Influence of Tillage and Deep Rooted Cool Season Cover Crops on Soil Properties, Pests, and Yield Responses in Cotton*. Open Journal of Soil Science , 6, 149-158. http://dx.doi.org/10.4236/ojss.2016.610015

Rosolem, C. A., K. Ritz, H. Cantarella, M. V. Galdos, M. J. Hawkesford, W. R. Whalley, and S. J. Mooney. 2017. *Enhanced plant rooting and crop system management for improved N use efficiency.* Advances in Agronomy 146: 205-239.

Slide 16 – *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. They also build stable SOM and absorb excess soluble N and other nutrients, thereby enhancing soil health and protecting water quality.

Large genetic variations among cultivars of a given crop species have been documented for root depth, biomass and branching pattern (architecture), leading to recommendations to breed crops for deep, bushy, high-biomass root systems as a means to sequester carbon and slow climate change.

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 17 – *Root biomass and drought resistance: an anecdotal example*

When transplanting lettuce starts from the flat, the gardener noticed that 'New Red Fire' starts had much larger, more consolidated root balls than other varieties such as 'Buttercrunch' or 'Red Salad Bowl." The plant in the photos was overlooked for a week of hot summer weather, during which it underwent severe wilting. Unlike most lettuce subjected to this kind of stress, this 'New Red Fire' recovered fully upon watering, and went on to produce a fine, marketable head a couple weeks later.

This example of New Red Fire lettuce from the presenter's home garden in Floyd, VA does not pass muster as a properly controlled variety trial. However, it may identify a promising entry into future summer lettuce trials, at least for the highly weathered loamy soils of the southern Appalachian region. On a contrasting soil type (e.g. semiarid region or peat soil), varietal responses may be very different.

Slide 18 – *Effective teamwork with soil microbes*

The capacity of plants to interact effectively with beneficial soil organisms may be significantly modulated by plant genetics. The example of N-fixing field corn was discussed earlier.

Slide 19 – *Induced systemic resistance (ISR) for tomato disease management*

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.

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 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.

Slides 20 and 21 – Plant genetics and root-microbe interactions: more examples

A growing body of research findings 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. 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 carrot cultivars to enter into effective symbiosis with mycorrhizal fungi. 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.

In a study of organic tomato fields in central California, researchers identified several with enhanced N use efficiency, in which soil microbes interacted with plant roots to stimulate expression of plant genes for enzymes involved in plant N uptake and assimilation.

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.

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.

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.*

Slide 22 – *Breeding cover crops for soil health*

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

Slide 23 – *Heritable traits in cover crops*

Erik Landry and colleagues at Washington State U identified four winter-hardy lines of small-seeded fava beans (bell beans) 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.

Organic grain farmers in Tennessee grow early-maturing 'Purple Bounty' hairy vetch and 'Abruzzi' rye and, 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

Slide 24 – *Breeding hairy vetch, crimson clover, and Austrian winter pea 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, working with other breeders and farmers to evaluate and select breeding lines in locations in each of the four major USDA regions in the US. OREI funded project 2015-07406, *Creating the Cover Crops that Organic Farmers Need: Delivering regionally adapted varieties across America*. CRIS Abstracts, http://cris.nifa.usda.gov/

Breeding priorities for the three winter legume covers are based on 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 the initial OREI grant 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.

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

Slide 25 – *Subheading: challenges in finding the best crop cultivars*

Slide 26 – *Challenge #1: today's crop 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.

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/

Slide 27 – *Challenge #2: cultivar choices are often 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 28 – *Challenge #3: public plant breeders are an "endangered species."*

Several recently-awarded OREI grants support project teams whose goals include training and establishing the next generation of public plant breeders in addition to developing and releasing new cultivars.

Slide 29 – *Challenge #4: intellectual property 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.

Slide 30 – *Challenge #4: intellectual property and breeders' rights to make a living*

The challenge here is 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.

Slide 31 – *Subheading: meeting the challenges.*

Slide 32 – *Farmer participatory plant breeding (PPB)*

Farmer-participatory plant breeding (PPB), an approach taken by Organic Seed Alliance, Mandaamin Institute, High Mowing Seeds, Common Wealth Seed Growers, and other non-profits and 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 avoids 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. Thus, for example, the CIOA project is selecting carrots for disease resistance, yield, and flavor, as well as weed competitive traits.

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 33 – *Northern Organic Vegetable Improvement collaborative (NOVIC)*

Slide 34 – *Student Collaborative Organic Plant Breeding and 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 35 – *Farmer-researcher collaboration*

This pea was identified in on-farm variety trials conducted through NOVIC.

Dr. Mazourek, Edmund Frost, and colleagues have worked together for over five years to identify, select, and develop cucumber, melon, and winter squash lines that combine resistance to major cucurbit diseases (downy mildew, powdery mildew, bacterial wilt) with plant vigor and yield, and flavor, nutritional value, and (for winter squash) shelf life. In addition to butternut squash (shown in photo), a new line of pickling cucumbers has shown promising resistance to both downy mildew and bacterial wilt in Edmund's 2018 field trials in Virginia.

Funding sources for this work include OREI, OFRF, and the USDA Southern Region Sustainable Agriculture Research and Education (SARE) program.

Slide 36 – *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 37 – *Subheading – tips for finding the seeds you need*

Slide 38 – *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 39 – *Sourcing and choosing organic seeds*

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, 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,

Southern Exposure Seed Exchange and Fedco Seeds catalogues offer hundreds of vegetable and other horticultural crop varieties, with excellent information on genetic traits such as disease or drought resilience, as well as market traits.

Slide 40 – *Cultivar descriptions – some examples*

This is some of the information that farmers need to choose the best cultivar for their goals and local conditions. Note that Danvers 126 is the carrot cultivar shown earlier, whose large tops shade out weeds and can reduce need for cultivation – provided that the crop is not attached by *Alternaria* leaf blight!

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

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 that ""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." From: https://seedalliance.org/2015/osas-abundant-bloomsdale-spinach-hits-marketplace/.

See the OFRF Soil Health / Plant breeding and genetics Guide for many more resources to help growers learn skills and get actively involved in plant breeding and securing a diverse organic seed supply for the future.

Slide 44 – *Subheading - Recent developments in public plant breeding for organic*

Slide 45 – *USDA funds plant breeding for organic*

Farmer-breeder networks launched through OREI funding include several already featured in this webinar: Northern Organic Vegetable Improvement Collaborative (NOVIC), Tomato

Organic Management and Improvement (TOMI), and Carrot Improvement for Organic Agriculture (CIOA).

Slide 46 – *OREI program news*

The OREI has provided a vital source of funding for public, classical (non-GMO) plant breeding endeavors, especially in vegetable crops. Given the long term time line of public cultivar development, release, and commercialization endeavors, it is especially encouraging to see the program's long term commitment to the most promising PPB networks, such as NOVIC, CIOA, and the cover crop breeding efforts.

The hiatus caused by not having a new farm bill or extension of the previous one when it expired at end of September, 2018 threatens to force OREI to suspend new awards for FY 2019. The good news is that both the Senate and the House versions of the 2018 Farm Bill included substantial increases in OREI funding, though only the Senate farm bill expands the program sufficiently (to $50 M/year) to give it permanent baseline funding. If this is realized in the final Farm Bill, it would greatly increase OREI's capacity to support plant breeding for soil health and profitable organic farming.

Slide 47 – *Looking into the near future*

TOMI advanced breeding lines (two) selected in field and via market assisted breeding for resistance to Late Blight, Early Blight, Septoria Leaf Spot, Bacterial Speck and Spot, Fusarium and Verticillium.

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 effect 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."