The Role of Plant Genetics in Soil Health: Selecting Crop Cultivars for Organic Production

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Presentation Notes

Slide 2 – *Can the right cultivars help organic farmers 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 contribute more directly to soil health by thoroughly covering the soil surface and adding abundant residues and root exudates.

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 corn cultivars.

Slide 3 – *Crop genetic traits that contribute to soil health*

Plant genetics play a major role in crop vigor, photosynthetic and growth rates, and partitioning between aboveground and root growth, as well as yield potential and resistance to pathogens, pests, and abiotic stresses such as drought. Many of these traits have significant implications for soil health.

Living plants feed the soil life and build organic matter throughout their life cycle (via root exudates and 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 and improving habitat for soil life.

Slide 4 – *Soil health and organic farming: the role of plant breeding and variety selection*.

Subheading slide.

Slide 5 – *USDA National Organic Program (NOP) Standards on cultivars and seeds.*

Genetic resistance to plant pathogens and nematodes is a major component of organic integrated management of these harmful organisms. The National Organic Standards Board (NOSB) has identified disease resistance as a leading research and plant breeding priority to help organic producers minimize their dependence on higher-impact NOP-allowed crop protection materials like copper and sulfur, which can have adverse impacts on soil health.

Slide 6 – *What organic farmers say about crop seeds*
Slide 7 – *Organic farmers' crop breeding priorities*

The information in these two slides is based on a survey of organic farmers conducted in 2020 by the Organic Farming Research Foundation and the Organic Seed Alliance (Hubbard et al., 2022; Snyder et al., 2022). Improving crop genetics for organic production can help address several leading production challenges identified by survey respondents, including nutrient management, diseases and pests, adapting to climate change, and co-managing weeds and soil health.

Slide 8 – *Desired traits for organic systems: soil benefits*

Vigorous crop cultivars that emerge and establish quickly, form a closed canopy early in the season, develop robust root systems, and leave sufficient residues to protect the soil after harvest make direct contributions toward building and maintaining soil organic matter (SOM) and soil health. Cultivars with greater capacity to establish and thrive in organic no-till or reduced till production systems despite some weed pressure can help organic producers minimize both chemical and physical soil disturbance and thereby further their stewardship goals.

Cultivars that make organic farming easier and more profitable in any way – overall ability to yield well under organic management, superior culinary and nutritional traits that improve market value, etc – indirectly benefit soil health and water quality by facilitating adoption of best organic production and resource stewardship practices.

Slide 9 – *Budgeting plant carbon for soil health and production*

Crop production and plant-based ecosystem services (SOM, soil life, carbon sequestration, etc) both depend on photosynthesis as the ultimate carbon and energy source. Hence, there is a potential tradeoff between yield/quality and soil health-enhancing traits such as high root biomass and exudation. Just as breeding and selection focused narrowly on maximum yield in conventional production systems has sometimes reduced the crop's ability to protect and build soil with residues and root biomass, selection for a single soil health trait such as root biomass can reduce yield and/or quality of the marketable product (Van Bueren, 2016). Thus, the most successful organic plant breeding endeavors take a systems approach and select simultaneously for multiple traits including satisfactory yield and high quality under organic management as well as above- and below-ground biomass and other ecosystem traits.

The tradeoff between production for market and photosynthetic product devoted to non-harvested parts of the plant and ultimately returned 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 and rhizodeposition (root exudates and fine root sloughing). With increased understanding of the importance of maintaining soil health, plant breeders now value what is returned to the soil as well as what goes to market.

Slide 10 – *Breeding crops to build soil health and meet organic market demand*

When the presenter (who plants a kitchen garden in his warm, rainy Appalachian climate each year) planted Edmund Frost's new cucumber with resistance to downy mildew and bacterial wilt, he harvested an abundance of cucumbers for the first time 20 years, and their flavor was outstanding. The 'South Anna' butternut squash rapidly covers the ground, unfazed by late-season weeds, and gives high yields of squash so sweet that one can cut the sugar in a pumpkin pie recipe by 50-65% for perfect flavor balance. Common Wealth Seed Growers of Louisa, VA offers these and other improved vegetable varieties at https://commonwealthseeds.com.

Slide 11 – *Desired cultivar traits for organic systems: soil benefits*

Disease-resistant crops need less copper, sulfur, and other potentially high-impact disease control materials currently allowed by NOP. Organic plant breeding endeavors have made substantial progress in developing new cultivars with multiple disease resilience. Weed-competitive cultivars need less cultivation and thereby help protect soil health. Nutrient- and water-efficient cultivars can cut production costs, reduce input needs, and thereby protect water resources.

Slide 12 – *Crop genetics for effective teamwork with soil microbes*

Research has confirmed that crop genetics modulate root biomass, depth, and architecture, and that a strong opportunity exists to optimize root development and functions (nutrient and moisture recovery, SOM accrual) through plant breeding and selection (Kell, 2011; Rosolem et al., 2017). Strong varietal differences in capacity to host and benefit from mycorrhizal fungi, nitrogen fixing bacteria, and disease-suppressive microbes have been identified in corn, cereal grains, sorghum, legumes, carrot, pepper, tomato, and some other vegetable crops (Cobb et al., 2016; Douds, 2009; Drinkwater and Grossman, 2018; Goldstein, 2015, 2016;; Hamel, 2004; Hoagland, 2018; Silva, 2016; Weil and Brady, 2017).

Slide 13 – *Heritable drought-resilience*

Southern Exposure Seed Exchange, https://www.southernexposure.com, based in central Virginia emphasizes organically or ecologically produced heirloom vegetable, herb, and grain seeds adapted to the mid-Atlantic and southeastern US, including some cultivars of tomato, peanut, cucumber, lima, okra, and other vegetables noted in the catalogue for their heat and drought tolerance. The importance of drought tolerance as a breeding objective for all agricultural systems will increase with climate change (Zystro and Silva, 2016).

The lettuce and tomato examples (photos D and E in the slide) are from the presenter's garden in Virginia. When transplanting lettuce starts from the flat, he 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 photo D was overlooked for a week during hot summer weather, and it wilted severely. Unlike most lettuce subjected to this kind of stress, the 'New Red Fire' recovered fully upon watering, and produced a fine, marketable head a couple weeks later.

Once established, this row of 'Juliette' grape tomatoes grew so vigorously that watering was stopped in midsummer. Yet, the crop grew to a height of seven feet and yielded abundantly (25 lb fruit per plant) until frost despite a "flash drought" that hurt late-summer crop production and pasture quality throughout Virginia.

Anecdotal examples like these do not pass muster as properly controlled variety trials, yet they may identify a promising lead for crop genetics suited for the warm rainy climates and highly weathered loamy soils of the southern Appalachian region – and for the increasingly erratic flood-and-drought patterns related to climate change. In other climates and soil types (e.g. semiarid region or peat soil), varietal responses may be very different.

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). These programs breed, select, and develop drought-resistant cereal grains, corn, rice, and beans in "managed stress nurseries" around the world.

Slide 14 – *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 (Byczinski, 2010). In the "dry farming" method practiced by some California farmers, irrigation is stopped after early crop establishment (for coastal areas with mild summers) or at flowering (hot summer regions) or limited to "deficit" rates during fruiting in drier areas. The cultivars 'Early Girl' and 'New Girl' (available through Johnny's Selected Seeds) have been found to perform best in the dry farming system in California, owing to their "aggressive and deep" root systems that enable to crop to access subsoil moisture soon after transplanting (EcoFarm, 2015).

Although the historic "atmospheric river" rain and snowstorms of winter 2022-23 have relieved California's 22-year drought, water conservation remains absolutely vital, because of the tremendous depletion of aquifers and the unknown future path of climate change.

Slide 15 – *Challenges in obtaining seeds and cultivars for organic systems*

Subtitle slide.

Slide 16 – *Challenge #1: Most modern cultivars are not designed for organic systems*

Organic growers must often compensate for the genetic limitations of today's cultivars, including poor competitiveness toward weeds, limited ability to utilize N from organic sources, no disease resistance or disease resistance based on a single gene that the target pathogen eventually overcomes through mutation and evolution (Hultengren et al., 2016). These weaknesses necessitate increased cultivation and heavier applications of organic fertilizers and NOP-allowed mineral based fungicides – 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 and require high N inputs to give competitive yields (Collins and Bary, 2017; Li et al., 2009).

The yield gap between organic and conventional production, estimated to average 19% for grains, can be attributed to a history of under-investment into organic systems research, especially the lack of crop cultivars developed for organic systems (Ponisio et al., 2014).

Slide 17 – *Have modern cultivars "forgotten" how to talk with soil life?*

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. Evidence is accumulating that 20th century breeding and selection for high input conventional production systems may have attenuated crop genetic capacity to recruit and support AMF, N-cycling and N fixing bacteria, and other organisms that help roots access nutrients from SOM or low-solubility sources, as well as natural enemies of pests and pathogens, and organisms that induce systemic resistance (ISR) to foliar and belowground pathogens. Examples include:

- Higher AMF colonization of sorghum land races vs modern hybrids that confer greater capacity for the land races to yield well on lower fertility soils (Cobb et al., 2016)
- Modern corn hybrids hosting non-pathogenic *Fusarium* that do not hurt the crop directly but deter the N fixing microbes that inhabit corn land race rhizospheres and can provide up to half of the corn's N requirement (Goldstein, 2016)

- Greater capacity of older *vs* modern corn varieties to release chemical signals, when corn rootworms attack the roots, to attract entomopathogenic nematodes such as *Steinernema* and *Heterorhabditis* applied as biopesticides (Hiltpold et al., 2010).
- Tomato land races with stronger ISR response to rhizosphere *Trichoderma* fungi than modern hybrids (Zubieta and Hoagland, 2017).

Restoring crop capacity to partner with beneficial soil microbes through plant breeding and selection in and for organic production systems constitutes a key plant breeding frontier; initial findings have been promising.

Slides 18 and 19 – *Addressing the challenge: breeding for organic systems*

The USDA National Institute for Food and Agriculture (NIFA) Organic Research and Extension Initiative (OREI) has supported robust, farmer-participatory plant breeding endeavors for a wide range of vegetable and field crops. Following is the full wording of Priority 4 (excerpted in slide 17) in the current (2023) Request for Applications (RFA):

> *4. Strengthen organic crop propagation systems, including seed and transplant production and protection, and plant breeding for organic production conditions, with an emphasis on publicly available releases. Goals of organic propagation and breeding-focused proposals can include, but are not limited to: disease, weed, and pest resistance; stress tolerance including resilience to drought, flood, extreme temperatures and other climate change impacts; nutrient use efficiency; performance in soil-improving and climate-smart systems such as organic no-till; quality and yield improvement; and genetic mechanisms to prevent inadvertent introduction of GMO traits through cross-pollination. This priority includes cover crop breeding for enhanced performance in organic systems. Projects dealing solely with cultivar evaluation do not fit under this priority."*

Since OREI funded research must be conducted on certified organic land (under organic management for a minimum of three years), and since NOP does not allow genetic engineering methods of cultivar development, these endeavors are based on breeding, selection, and evaluation in fields under organic management. Thus, the resulting new breeding lines and cultivars will have enhanced overall adaptation for organic systems in addition to the specific traits being selected for.

Several farmer-plant breeder networks have received two or three successive OREI awards allowing an extended (8-12 year) period of plant breeding research and cultivar development. With increased funding for OREI ($50 million permanent baseline mandatory funding as of 2023), the capacity of OREI to support ongoing efforts to develop improved crop cultivars for organic systems has been further expanded.

Slide 20 – *Challenge 2: Cultivar choices are limited and often not suited for organic*

Organic producers struggle to find the seeds they need for several reasons:

- Seed industry consolidation has degraded crop genetic diversity, and many heirloom and regionally adapted cultivars have been lost (Shelton and Tracy, 2016).
- Many modern cultivars of major commodity crops have been developed with NOP-excluded genetic engineering (GMO) methods.
- Corporate seed businesses prioritize "big" targets (corn, soy, etc) and do not invest in "minor" crops or regionally adapted cultivars for organic production (van Bueren, 2016).

Slide 21 – *Addressing the challenge: 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 as well as several land grant universities, is a highly effective 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. PPB encourages a systems approach to advance multiple priorities (e.g. flavor, disease resistance, and cold tolerance for corn in cold-temperate climate), rather than focusing on single traits. The Collaborative Plant Breeding Network for Organic Systems in the Upper Midwest (Dawson et al., 2022) delivered a series of six webinars in early 2023 providing practical training in collaborative on-farm organic plant breeding for farmers, plant breeding students, regional seed companies, and other independent plant breeders, available at https://eorganic.org/node/35654.

Farmer breeders and seed savers working with scientists to develop improved cultivars for organic production systems play a central role in conservation of the world's plant resources.

> *"Dozens of farmer-bred varieties are currently offered in organic seed catalogs."* (Hubbard and Zystro, 2016, p 21)

> *"More than 70% of the organic seed research projects … involved farmers. One researcher shared, 'We could not do this project without [farmer] involvement. Helpful is not a strong enough word. They are required partners.'"* (Hubbard and Zystro, 2016, p 26)

Slide 22 – *Resource: Organic Seed Alliance https://seedalliance.org.*

2024 Organic Seed Growers Conference https://seedalliance.org/conference/.

Organic Seed Commons is an online networking platform for commercial seed producers, cultural seed keepers, on-farm plant breeders, university researchers and plant breeders, and beginning or experienced seed savers to share information, findings, and ideas, and to amplify and facilitate the work of developing and providing the seeds that organic farmers need. Apply here.

Slide 23 – Challenge #3: public plant breeders are an “endangered species”
Slide 24 – Addressing the challenge: training the next generation of organic plant breeders
Slide 25 – Student Collaborative Organic Plant Breeding Education (SCOPE)

The public plant breeding sector has undergone severe downsizing over the last few decades due to underfunding, and an urgent need exists to recruit and train the next generation of plant breeders (Hubbard and Zystro, 2016). Thanks in large part to OREI, this decline has begun to reverse for organic plant breeding, as more and more teams of University, NGO, ARS, small seed company, and independent farmer plant breeders receive funding to undertake public cultivar development for organic systems (Hubbard et al., 2022).

OREI has funded several projects whose goals include training college and graduate students in plant breeding for organic producers as well as development of new crop cultivars for organic producers. In 2015, Julie Dawson at University of Wisconsin received OREI funding (award 2015-51300-24151) for a Student Organic Seed Symposium, held in 2016. Project activities and outcomes included:

- A conference that brought grad students in organic plant breeding together with LGU faculty, representatives from small seed companies and NGOs, and farmers in a network of training and support.
- The 3-day conference included presentations, tours of three leading organic farms, a seed exchange with breeding lines and rare materials, and in-depth informal networking leading to long-term collaborations.
    - A team of 6 students at this event are organizing the next SOSS in Davis, CA, 2017.
- Prior to the conference, 19 students sent seeds from their organic breeding projects in a wide range of crops - carrot, beet, watermelon, tomato, onion, barley, green and dry beans, pepper, corn, cotton, kale, oats, wheat, and quinoa - to be grown at Johnny’s Selected seeds and viewed, shared, and discussed at the conference.

Student Organic Seed Symposia (SOSS) have been held annually. In 2020, Cara Loriz of Organic Seed Alliance received an OREI conference grant to collaborate with U Wisconsin and thereby expand the reach of the SOSS. The event was held at West Virginia University in July 2022 (postponed one year because of the pandemic), and engaged 60 student and faculty plant breeders, rural sociologists, agroecologists, farmers, and seed industry stakeholders in networking, presentations, and field demonstrations of new cultivars. Topics included wheat, barley, beets, dry beans, sweet corn, dry corn, tomatoes, and regional seed initiatives focusing on southern peas, okra, collards, and culturally significant varieties of corn.

In 2015, E. Charles Brummer at University of California at Davis received OREI funding for a project entitled *An experiential learning-based public plant breeding pipeline for organic cultivar development*. This project became the Student Collaborative for Organic Plant Breeding Education (SCOPE), which combines two goals: developing new crop cultivars for organic producers and training the next generation of plant breeders for the organic sector.

Northern California organic farmers and seed producers work closely with UC Davis graduate and undergraduate students and faculty to identify priorities and develop new farmer-ready public cultivars to meet those needs. Students receive experiential training in classical breeding methods, from identifying useful germplasm and making crosses to evaluating breeding lines in a diversity of fields at working organic farms and research stations and developing finished cultivars. Students work with a range of crop types and plant life cycles that require different breeding strategies: tomato, pepper, dry common and lima beans, wheat, and zinnia. SCOPE received additional funding in 2020 to continue and expand its student training and cultivar development endeavors.

SCOPE accomplishments include release of six new dry bean cultivars in 2020 that combine heirloom flavor with enhanced disease resistance and yields under organic management. In addition, the project has developed two large-cavity stuffing jalapeno cultivars and one sunscald-resistant yellow bell pepper cultivar. All three have outyielded standard cultivars under organic management and were scheduled for release in 2022.

Slide 26 - *Intellectual Property Rights (IPR): seed patenting*

The increasing imposition of utility patents on crop cultivars can become a substantial hindrance to the development of new and improved cultivars for both organic and non-organic production systems. As the climate crisis unfolds and market conditions evolve, *all* farmers need greatly improved access to a diversity of well-adapted crop seeds to meet ongoing and ever-shifting production challenges. The more germplasm is locked up in utility patents held by private interests, the fewer resources that farmers and public plant breeders will have to develop new, publicly available cultivars to meet organic farmers' needs and today's challenges.

While patents on GMO seeds have little direct impact on organic producers because NOP prohibits GMO seeds, increasing IPR restrictions on non-GMO cultivars and breeding lines can become a serious barrier to farmer-participatory public plant breeding.

Slide 27 – *Addressing the challenge: open source seed initiative (OSSI)*
Slide 28 – *Addressing the challenge: intellectual property and plant breeders' livelihoods*

The Open Source Seed Initiative (OSSI) takes the opposite extreme from utility patents, affirming all OSSI seed as part of the genetic commons that cannot be privatized or appropriated in any way. While this idea has much merit, some seed professionals are concerned that widespread application of OSSI principles to plant breeding and seed production has the potential to restrict plant breeders' ability to make a living in their line of work. This, in turn, would become a serious deterrent to the kind of innovation in cultivar development that organic and other farmers so urgently need at this time to make a living, meet the challenges of climate change, and fully realize their soil, climate, and resource stewardship goals.

The challenge here is to:
1 - make seed available to producers at reasonable cost and without intellectual property rights restrictions against on farm seed saving

2 – provide a viable living for the scientists and plant breeders who develop and release public cultivars, and
3 – provide sustained funding for robust plant breeding programs over the long run.

The Plant Variety Protection Act (PVPA) provides a reasonable compromise: farmers can save and replant seed on their own farms but cannot sell the seed for profit. Plant breeders including farmers can use PVP cultivars as a source of germplasm to make crosses and develop new breeding lines and cultivars. University and NGO plant breeders can also develop other intellectual property arrangements that ensure fair compensation for breeders without unduly restricting farmers' rights to save and select seed.

Slide 29 – *Organic plant breeding research: vegetable crops*

Subtitle slide

Slides 30-31 – *Northern Organic Vegetable Improvement Collaborative (NOVIC)*

Funded through three successive OREI grants in 2010, 2014, and 2018, NOVIC has conducted farmer-participatory breeding of many vegetable crops through several network hubs across the northern US from WA to NY. Selected primarily for flavor, keeping quality, resistance to major diseases and abiotic stresses, and earliness as well as overall performance under organic management, a number of NOVIC cultivars are now offered through seed catalogues and more are under evaluation for potential commercialization.

NOVIC 3 (award in 2018) prioritized tomato, pepper, winter squash, cabbage, sweet corn, and cucumber, and individual network hubs added farmers' regional priorities including carrots, beans, zucchini, and dry corn for tortillas.

From the final report:

> *"Cornell tested new downy mildew resistant cucumber hybrids, that exhibited highly competitive yields and unsurpassed disease resistance, multiplied seed and released them to seed companies for commercial evaluation. We multiplied and performed the final selection on early, short season peppers and shared for pre-release evaluations with seed companies and growers."*

Slides 32-34 – *Carrot Improvement for Organic Agriculture*

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 agronomic and market traits of vital importance to growers. The team has developed varieties and breeding lines with a rainbow of different colors and good flavor and has identified and integrated new genetic sources of resistance to several species of root knot nematode (Simon et al., 2016a, 2016b, 2021). Researchers also documented genetic variation among carrot cultivars in capacity to associate with mycorrhizal fungi and beneficial endophytic bacteria, and found that organically managed soils enhance the diversity and abundance of these beneficial symbionts (Abdelrazek, 2018; Abdelrazek and Hoagland, 2017; Silva, 2016). Other researchers have recommended breeding crops for enhanced mycorrhizal symbiosis (Hamel, 2004).

The current project (OREI award 2021-51300-34900) takes a deeper dive into the interaction of plant genetics, rhizosphere (root zone) and endophytic (within root tissue) microbiomes, and functionality of the plant-microbe partnership including nutrient uptake, disease and nematode resistance, and ability to exclude or minimize heavy metal uptake in urban production environments. The project is also expanding collaboration with farmers across the US through its NGO partner Organic Seed Alliance (OSA). Ongoing cultivar development focuses on both agronomic and market traits and will keep project outcomes in the public domain. Some quotes from the proposal and first annual report (Simon et al., 2022) follow:

> *"Focus area 1: Cultivar release: [S]eed will be increased on collaborating organic seed farms in WA, released to organic seed companies in Years 2-4, and promoted through outreach, participatory trials, and culinary evaluation activities. Three new varieties bred during CIOA 1-2 are now ready for commercial release. [One] is now available commercially from High Mowing Organic Seeds under the name Carnelian. Other releases are advancing to commercialization.*
>
> *"Public domain release and protection of new cultivars: McCluskey and Hubbard [Organic Seed Alliance] will lead the building and launch of the new Plant Prior Art Repository (PPAR). Publishing plant varieties and traits in the repository puts these inventions into the public domain and protects them from patenting.*
>
> *"Focus area 2: Expand participatory variety trialing and plant breeding network. … At least 10 organic farmers and smaller scale organic seed companies will partner with the breeding team to … commercialize new varieties and at least 40 farms per year will participate in decentralized on-farm variety trials nationally …[coordinated through the on-line platform] SeedLinked.*
>
> *"OSA hosts a new network through the Organic Seed Commons. The project created a carrot breeding synergy group within the OSC for coordinating trialing and education, currently for 16 members.*
>
> *"Focus area 3: Investigate links between microbiomes, nutrient uptake, pathogen resistance, and root nutritional quality and storability among carrot genotypes. [Research station and on-farm trials] evaluate whether carrot cultivars release chemically distinct root exudates that recruit specific strains of rhizosphere bacteria and fungi, which together can result in differences in carrot growth and quality.*
>
> *"Research started in CIOA2 investigating relationships between carrot genotype, root microbiomes, and heavy metal uptake was continued with a second round of field trials on 10 urban farms across Indiana. Webinar [part of series on nurturing city soils for healthy*

organic vegetables] Combining soil amendments and varietal development to prevent pathogens and heavy metal uptake https://eorganic.org/node/35542.

"Focus Area 4: Utilize molecular markers to improve nematode resistance. One new nematode resistance source was identified with M. incognita [southern root knot nematode] resistance.

"Focus Area 5: Evaluate and improve carrot flavor, texture and color. Assessment of carrot flavor was integrated into all germplasm evaluations and breeding activities since flavor is a priority trait necessary for the successful adoption of new cultivars with quality agronomic traits. Webinar Breeding carrots for production, resilience, flavor and fun in organic systems. https://eorganic.info/node/35336.

Slides 35-36 – *Tomato organic management and improvement (TOMI)*

In the Tomato Organic Management and Improvement project (OREI awards 2014-51300-22267 and 2019-51300-30245), researchers and plant breeders at Purdue University, University of Wisconsin, and Organic Seed Alliance are working with farmers to develop effective organic IPM for multiple foliar diseases of tomato including early blight (*Alternaria solani*), Septoria leaf spot (*Septoria lycopersici*), gray mold (*Botrytis cinerea*) and late blight (*Phytophthora infestans*). Major components of the IPM strategy include:

- Develop new tomato cultivars with durable (multi-gene) disease resistance and excellent flavor through farmer-participatory plant breeding.
- Identify and utilize effective biofungicides to reduce the need for copper, thereby protecting soil and water resource from excessive copper levels.
- Identify soil management practices and tomato cultivars that facilitate expression of induced systemic resistance (ISR) to foliar pathogens.

Studies of tomato resistance to late blight and gray mold demonstrated that a tomato land race ('Colombia') responds 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; Zubieta and Hoagland, 2017). 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.

The second funding cycle (TOMI 2) includes a focused effort to better understand the role of tomato genetics in promoting specific rhizosphere microbes that directly suppress pathogens via antibiotic or antifungal capabilities and indirectly via ISR. The project team is now integrating ISR traits protective against late blight and gray mold into the tomato breeding program.

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) and pathogens often mutate and evolve to overcome the resistance gene. "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. The reduced need for copper in organic tomato production will directly benefit soil health and water quality, while the improved yields and net returns from disease-resistant, high-quality tomatoes will further reduce the per-pound environmental costs and climate impacts of organic production.

Slide 37 – *Organic plant breeding research: grains*

Subtitle slide.

Slides 38-39 – *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 they 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 approaching those of 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, 2015, 2018). Mandaamin Institute made seed available to growers and scientists through cooperative licensing agreements.

Research findings suggest that breeding and selecting modern corn hybrids *in* and *for* conventional systems with high N inputs has modified the relationships between corn roots and soil microbes so that non-pathogenic *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 the crop's ability to fix N and utilize N from organic materials. A few years' seed increase under organic (versus conventional) management has improved the resilience of breeding lines to low soil soluble N.

An OREI-funded University of Illinois organic corn breeding project developed a farmer-participatory network to develop "high-yielding, nutritious, N use efficient, weed-competitive genotypes adapted to organic systems" (Ugarte et al., 2022). The team compared the performance of corn cultivars from Mandaamin Institute and three other breeding programs, and found that the Mandaamin corn yielded somewhat less than cultivars from two of the other programs. They also investigated the relationship between root architecture and overall performance and found:

- Lower yield in cultivars with a “complex” root system with highly branched coarse roots and higher root biomass.
- Higher yield in cultivars with deeper roots, which may improve drought resilience.
- A negative relationship between abundance of coarse roots and fine roots, suggesting a positive relationship between fine roots and yield, possibly because of more efficient nutrient uptake through fine roots.

Slide 40 – *Salt-tolerant Rice for Coastal Plain Affected by Sea Level Rise*

Sea level rise related to climate change has increased the salinity of tidal rivers along the southeastern US coastal plain and increased the frequency of saltwater flooding of agricultural lands near the coast. Researchers at Clemson University received a grant from the USDA Organic Transitions program (ORG) to address the resulting challenges faced by the region’s organic rice farmers (Ward et al., 2022).

The project team has evaluated rice cultivars for salt tolerance and conducted initial crosses between the two most tolerant entries and the commercial standard ‘Carolina Gold,’ which has been grown in the region since the 1690s. Progeny will be evaluated and selected over a total of eight generations to develop new salt-tolerant breeding lines with the yield, quality, and culinary traits of Carolina Gold.

Greenhouse trials are underway to evaluate the impacts of rice cultivar and salinity levels on the competitive interaction of organically grown rice with two common weeds of the region’s rice fields: hemp sesbania and goosegrass. Soil health and water quality benefits of organic rice production will be documented. In the third and fourth years of the project, on-farm trials will be conducted on six organic rice farms that have suffered impacts of salt intrusion, and an economic analysis of organic rice production in salt-affected coastal plain soils will be conducted.

Slide 41 - *Breeding and agronomy of quinoa for organic systems*

This project made substantial advances toward development of improved quinoa (*Chenopodum quinoa*) cultivars for organic production and best organic production practices in agro-ecoregions across the US (Murphy, 2021). The team engaged farmers and Indigenous communities in the project, gave multiple conference presentations and has published or will publish key findings. Although the genus *Chenopodium* is generally considered non-hosts for mycorrhizal fungi, the study confirmed that quinoa breeding lines hosted mycorrhizal fungi as well as beneficial phosphorus-solubilizing and N-fixing bacteria to varying degrees. An extensive analysis of the microbiome of cultivars and breeding lines was conducted.

Nutritional value of quinoa as a complete protein food emerged as a top breeding and selection priority, and protein content and end use quality were evaluated. The team also conducted an economic analysis of integrating quinoa into organic field crop rotations. Results suggest that, with improved cultivars and production practices, quinoa can become a viable and profitable crop for organic producers seeking to diversify their rotations and meet the robust market demand for high quality, domestically produced, organic quinoa.

Slide 42 – *Organic plant breeding research: cover crops*

Subtitle slide

Slide 43 – *Breeding cover crops for soil health*

Cover crops are grown primarily to protect soil and water resources and to enhance soil health. Organic farmers especially rely on cover crops to provide and manage nutrients, build and maintain soil organic matter and beneficial soil life, suppress weeds, and provide habitat for natural enemies of crop pests.

Desirable traits for cover crops include rapid emergence and establishment; early canopy closure and weed competitiveness, high biomass, strong nitrogen fixation (legumes) or nutrient recovery (catch crops). Many of these capabilities are modulated by crop genetics, and breeding and selecting cover crops for organic systems is now included in OREI RFA priorities.

Slide 44 – *Examples of heritable traits in cover crops*

Plant breeders at Washington State University identified four winter-hardy lines of small-seeded fava beans (bell beans) and further improved their hardiness through selection over four years (Landry et al., 2015). The improved lines, with 32 – 43% survival to -12°F, were registered in 2015 and made available to plant breeders for further development into finished cultivars.

Organic grain farmers in Tennessee grow early-maturing ‘Purple Bounty’ hairy vetch and ‘Abruzzi’ rye, which allows timely roll-crimping for no-till corn and soybean planting. They have also observed that ‘Purple Bounty’ is easier to kill by roll-crimping than other hairy vetch cultivars or VNS seed.

Slide 45 – *Nationwide cover crop breeding network*

Initially launched in 2015 through an OREI grant to ARS Beltsville, MD (Mirsky, 2020), the National Cover Crop Breeding Network, now led by Moore et al (2022) is the nation’s largest cover crop breeding endeavor. Hairy vetch, crimson clover, Austrian winter field pea, and (starting in 2021) cereal rye accessions are undergoing evaluation, breeding, and selection for traits important to the functions of cover crop in organic systems, including vigor and biomass, weed competitiveness, winter hardiness, time of flowering and maturity, and seed yields. Working at multiple sites in 13 states from Wisconsin to Texas, Washington to North Carolina, the project team has developed advanced breeding lines of the three legumes, several of which will be released soon. An additional trial was initiated in Alaska in 2022-23 to test cover crop survival through extreme winter cold.

The project is also developing a variety trial database to help farmers select the best cover crop varieties for their climates, soils, and production systems.

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