

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



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USDA  
Natural Resources  
Conservation Service

# Mark Schonbeck

Mark Schonbeck has worked for 35 years as a researcher, consultant, educator, and advocate for sustainable and organic agriculture. He works one-on-one with farmers and homesteaders, taking a site-specific approach to soil test interpretation and organic soil, nutrient, and weed management for vegetables and other crops. In his capacity as Research Associate with Organic Farming Research Foundation, he develops research-based education materials including a series of practical guides on *Soil Health and Organic Farming*, available at <http://ofrf.org/>.

In the past, Mark has led or participated in several on-farm research projects conducted by Virginia Association for Biological Farming and collaborated with them and National Center for Appropriate Technology to help our agency Natural programs better serve organic producers.

Mark also serves as policy liaison with National Sustainable Agriculture Coalition. He also works with OFRF to develop policy recommendations to help organic producers mitigate the impacts of climate change on their operations and the communities they serve.



# Can the right cultivars help organic farmers build healthy soils?

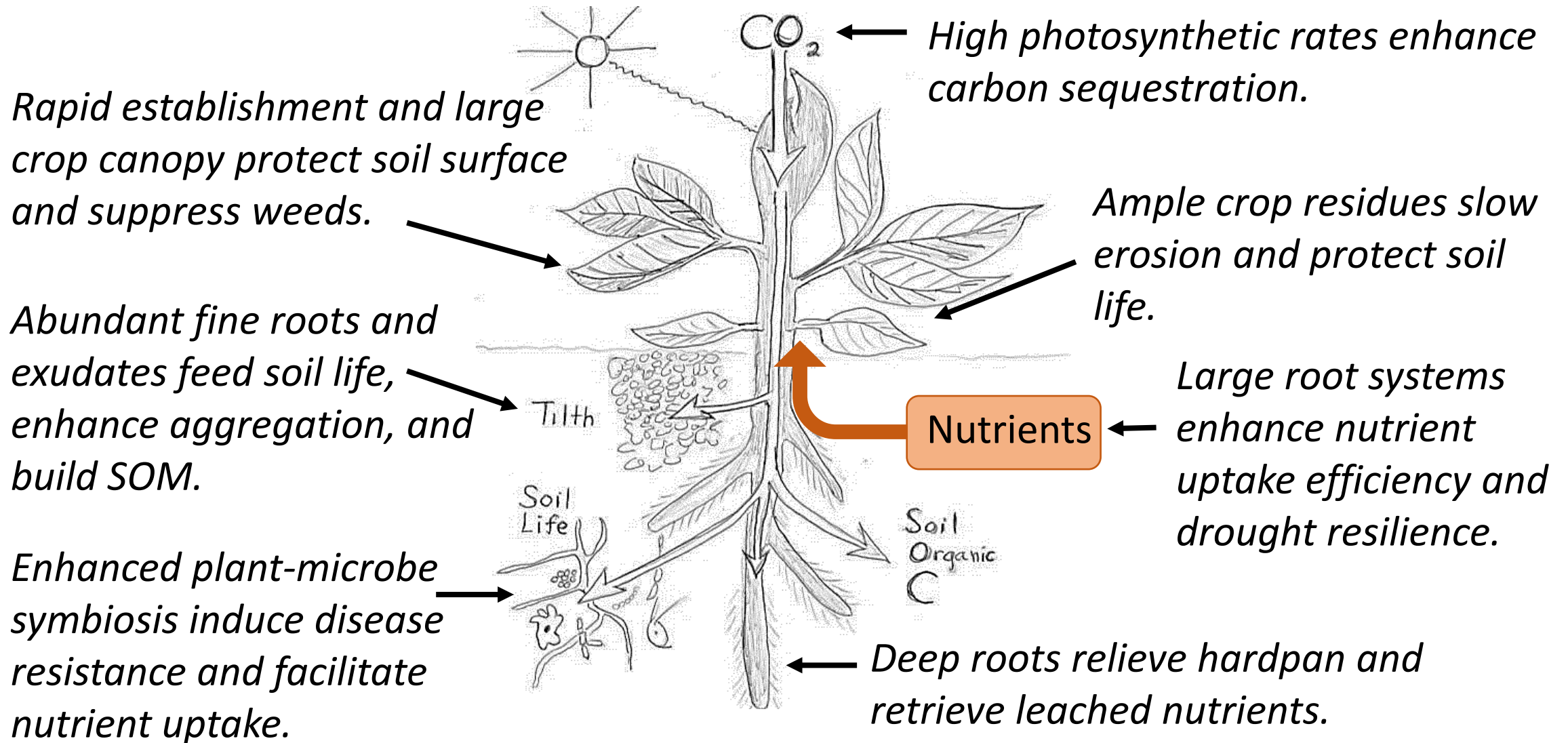
Yes, if heritable traits:

- Facilitate resource-conserving organic production.
- Confer resilience to locally prevalent diseases, pests, and other stresses.
- Reduce need for fertilizer, water, and other inputs.
- Reduce erosion, build soil organic matter (SOM), and improve tilth.
- Support beneficial soil organisms and optimize plant root-soil-microbiome partnerships.



*'Who Gets Kissed?' bicolored sweet corn offers earliness, disease resilience, and great flavor.*

# Crop Genetic Traits that Contribute to Soil Health



# Soil Health and Organic Farming

The role of plant breeding and variety selection

# USDA National Organic Standards on Cultivars and Seeds

*The producer must use organically grown seeds, annual seedlings, and planting stock. Non-organically produced, untreated seeds and planting stock may be used ... when an equivalent organically produced variety is not commercially available.*

*The producer must use management practices to prevent crop pests, weeds, and diseases, including ... selection of plant species and varieties with regard to suitability to site-specific conditions and resistance to prevalent pests, weeds, and diseases.*

USDA National Organic Program (NOP) Regulations, §205.204 Seeds and planting stock, §205.206 Crop pest, weed, and disease management

# What Organic Farmers Say About Crop Seeds



## 2022 NATIONAL ORGANIC RESEARCH AGENDA

*Outcomes and Recommendations from the 2020 National Organic & Transitioning Farmer Surveys and Focus Groups*



*By Lauren Snyder, Mark Schonbeck, and Thelma Velez Brise Tencer, Project Director*

- Finding appropriate crop varieties and seeds for organic production is challenging for 38% of survey respondents, including:
  - 62% of Southern region organic farmers.
  - 47% of transitioning-organic farmers.
- 44% report that lack of organic seed with desired traits may lead them to buy non-organic seed.
- 86% consider crop varieties bred for organic important for successful organic farming.
- 83% consider organically grown seed important for integrity of organic food.
- 74% consider unintended planting of GMO-contaminated seed a significant risk.

# Organic Farmers' Crop Breeding Priorities



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- Restore crop genetic diversity and adaptability to region, site, and management system
- Tomatoes, brassicas, cucurbits, berries, carrots
- Corn, soybean, wheat, alfalfa
- Cover crops, including for organic minimum till
- Yield under organic management
- Weed competitiveness and nutrient efficiency in field crops
- Disease resistance and heat tolerance in vegetable crops
- Ability to exclude GMO pollination

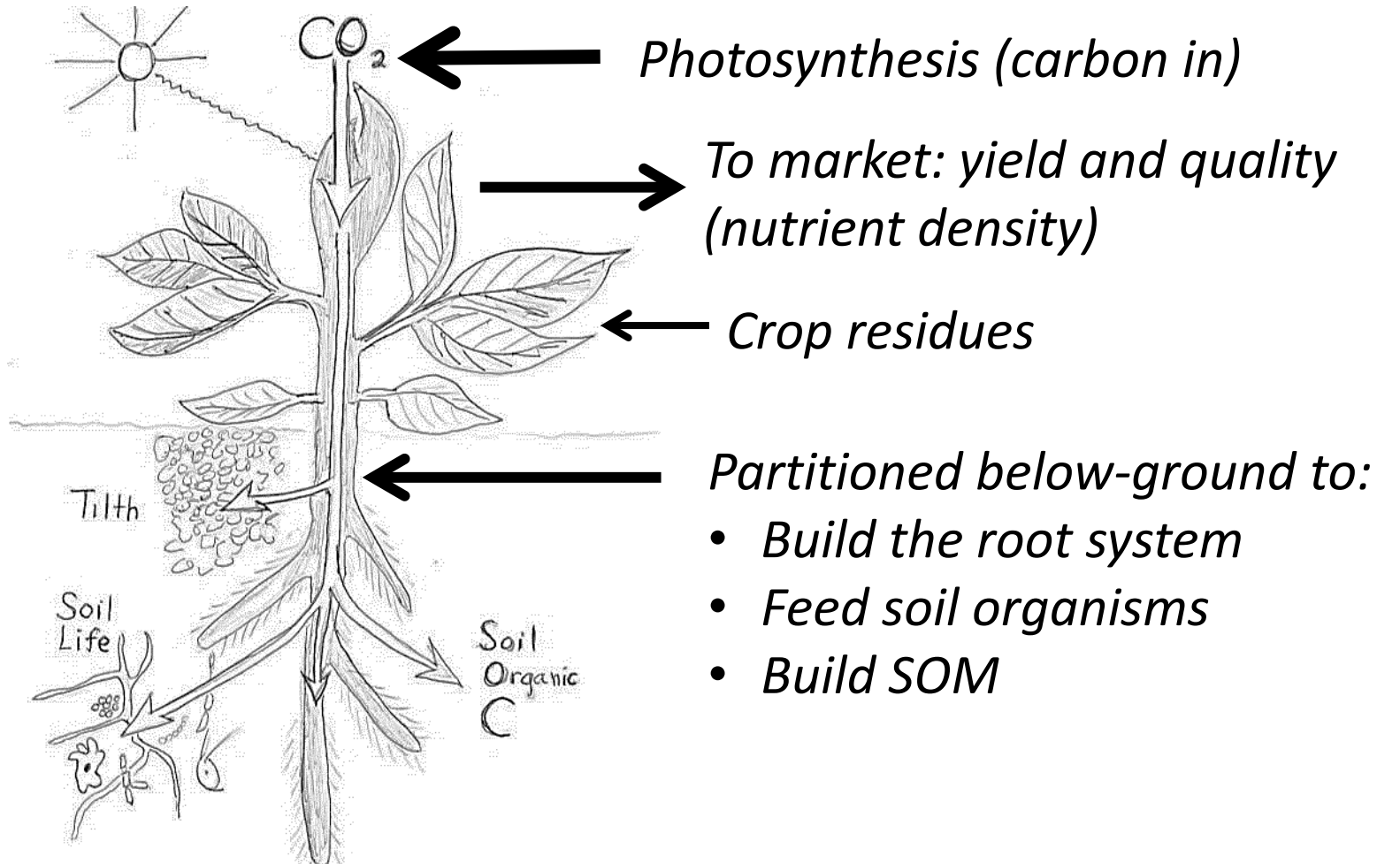
# Desired Cultivar Traits for Organic Systems: Soil Benefits

Cultivar Traits	Soil and water benefits
Improved yield in organic systems	Facilitates organic farming and reduces environmental cost per unit production
Rapid establishment and canopy closure, high biomass, robust root system	Reduces soil erosion, feeds soil life, builds SOM and soil structure
Ability to establish and thrive in organic minimum-till	Facilitates practices that minimize physical and chemical soil disturbance
Market values: flavor, color, culinary and nutritional value, keeping quality	Farms prosper and can afford to adopt advanced soil stewardship practices

# Budgeting Plant Carbon for Soil Health and Production: *Breeding for Optimum Partitioning of Photosynthetic Product*

## Tradeoff:

Marketable yield  
and product quality  
*versus*  
Organic inputs to  
the soil



# Breeding Crops to Build Soil Health and Meet Organic Market Demand



*Robust sweet potato and winter squash crops cover, protect, and feed the soil (left). 'South Anna' butternut squash (center) and an advanced cucumber breeding line (right) combine vigor, disease resistance, high yields, and superb flavor. Cultivars developed by organic farmer and plant breeder Edmund Frost of Common Wealth Seed Growers.*

# Desired Cultivar Traits for Organic Systems: Soil Benefits

Cultivar Traits	Soil and water benefits
Enhanced association with mycorrhizal fungi and other beneficial microbes	Enhances <u>all</u> the following traits and benefits
Disease and nematode resistance	Reduces need for fungicides and nematicides, protects soil life
Weed tolerance and weed competitiveness	Reduces need for cultivation, protects soil life, SOM, and soil structure
Drought resilience, water use efficiency	Conserves water resources
Nutrient use efficiency, N fixation	Reduces need for fertilizer, protects water quality

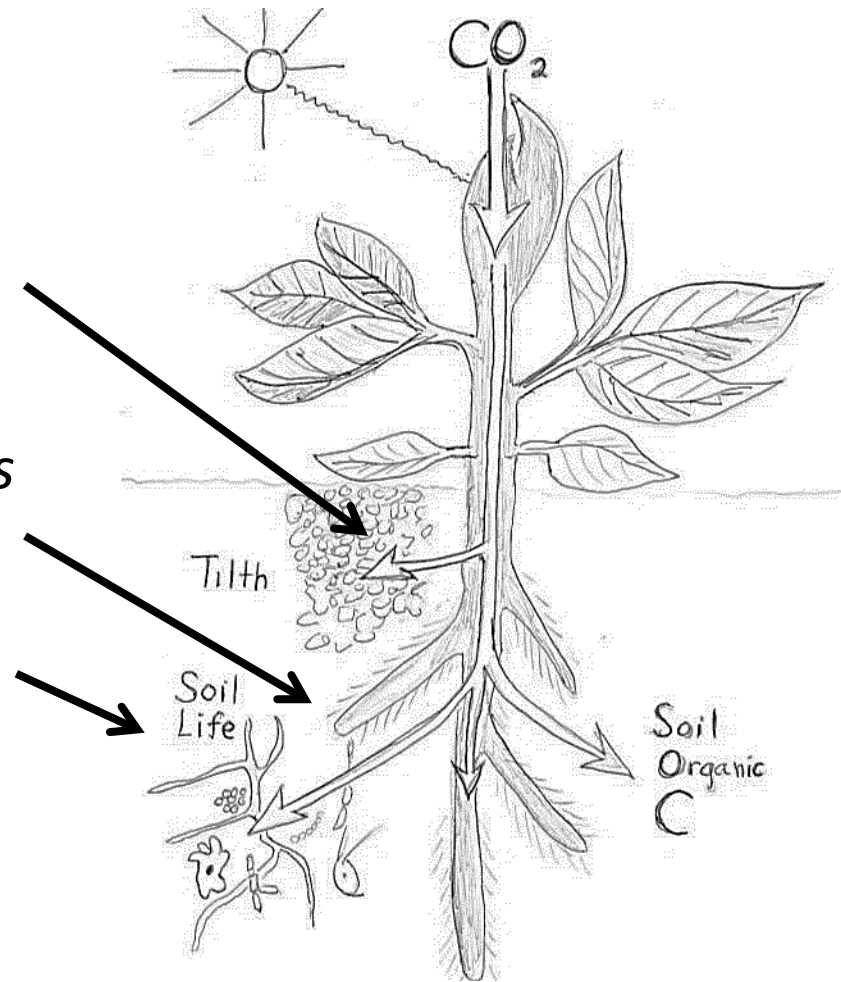
# Crop Genetics for Effective Teamwork with Soil Microbes

*Enhanced quantity and quality of root exudates*

*Specific chemical signals to beneficial organisms*

*Enhanced microbiome:*

- *N fixers*
- *Mycorrhizae*
- *Disease antagonists*
- *Other*



Variation among cultivars in capacity to host beneficial rhizosphere and endophytic microbes that:

- Aid nutrient and moisture uptake.
- Fix nitrogen.
- Suppress or consume pathogens and pests.
- Induce systemic resistance to foliar pathogens.

# Heritable Drought Resilience



*Drought-hardy cultivars of okra (A), pepper (B), lima bean (C), and other vegetables are offered by seed companies who specialize in seeds for organic systems. 'New Red Fire' lettuce (D) had markedly larger root mass at transplanting than other cultivars and maintained quality in 85-degree heat. 'Juliette' tomato (E) yielded 25 lb per plant during a dry summer in Virginia with minimal irrigation.*

# Growing Tomatoes on Less Water

- ‘Arkansas Traveler’ yields “flavorful tomatoes [in] drought and high heat where many other varieties fail.” (*Southern Exposure Seed Exchange* catalog)
- Some California growers are “dry-farming” tomato to improve flavor and save on irrigation costs. Yields dip somewhat while flavor improves.
- ‘Early Girl’ and ‘New Girl’ are especially well suited for dry farming, as their deep, vigorous root systems readily access subsoil moisture.
- Climate change has made drought resilience and water use efficiency top priority breeding goals.



*Tomato cultivars vary in drought tolerance and irrigation needs.*

# Challenges in Obtaining Seeds and Cultivars for Organic Systems

Resources to address those challenges

## Challenge #1:

# Most Modern Cultivars are not Designed for Organic Systems

*“Cultivars are most productive under the conditions for which they were bred ... [C]ultivars bred under conventional management – aided by synthetic fertilizer, herbicides and pesticides – will likely not be as productive under organic management.”*

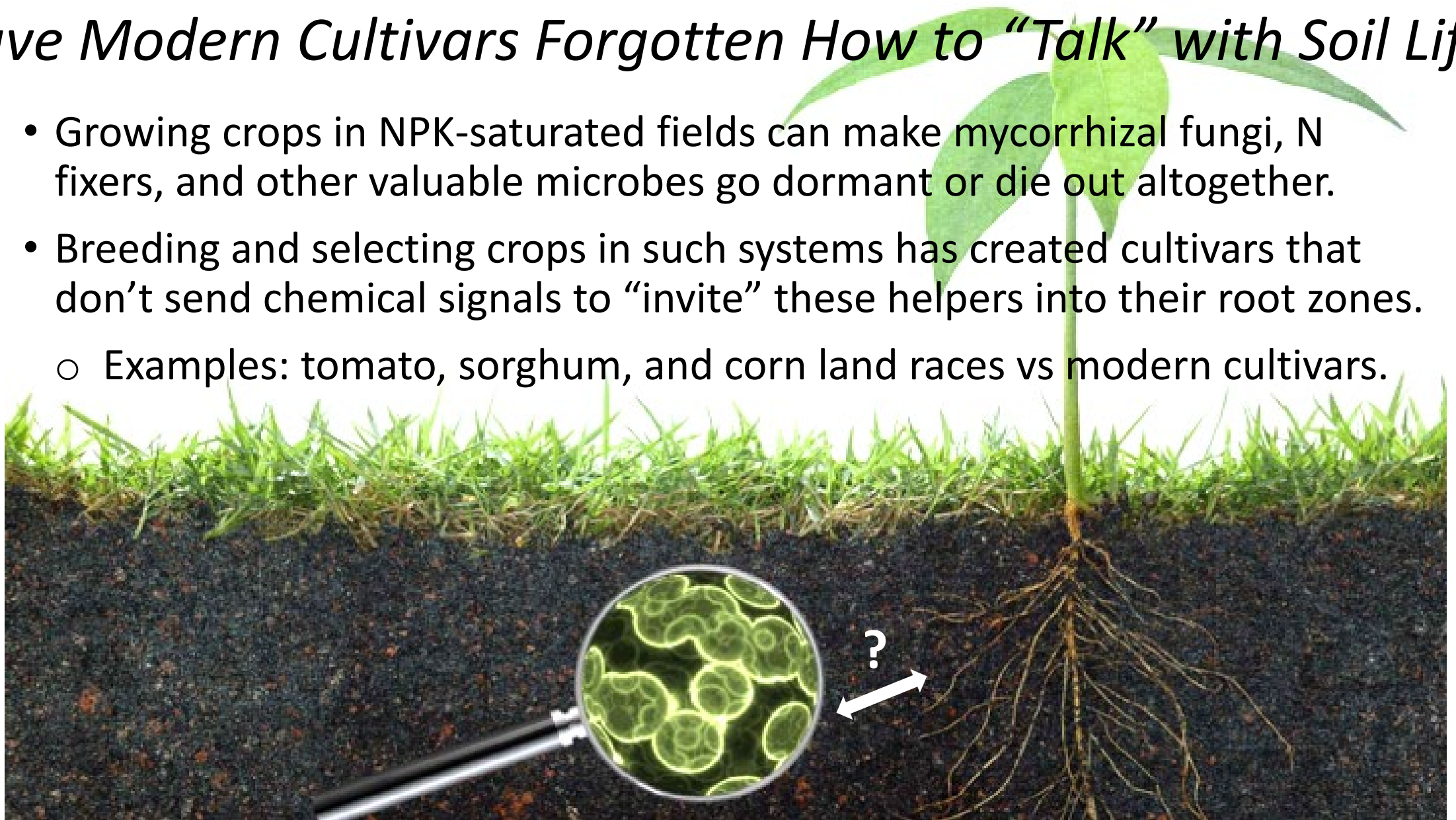
Hultengren, et al., 2016. Organic Seed Alliance,  
<http://www.seedalliance.org/>.



*Today’s broccoli cultivars can be grown organically but require >200 lb N/ac for optimum yield. Half of this N is lost to leaching or denitrification.*

# *Have Modern Cultivars Forgotten How to “Talk” with Soil Life?*

- Growing crops in NPK-saturated fields can make mycorrhizal fungi, N fixers, and other valuable microbes go dormant or die out altogether.
- Breeding and selecting crops in such systems has created cultivars that don't send chemical signals to “invite” these helpers into their root zones.
  - Examples: tomato, sorghum, and corn land races vs modern cultivars.



# Addressing the Challenge: Breeding for Organic

Organic Research and Extension Initiative (OREI) RFA priorities include:

*“Strengthen organic crop propagation systems, including ... plant breeding for organic production conditions ... publicly available releases. Goals include:*

- *Disease, weed, and pest resistance*
- *Stress tolerance including resilience to [impacts of] climate change*
- *Nutrient use efficiency*
- *Performance in soil-improving and climate-friendly systems such as organic no-till*
- *Quality and yield improvement*
- *Genetic mechanisms to [exclude] GMO pollen.*
- *Cover crop breeding for enhanced performance in organic systems.”*

*OREI 2023 Request for Applications*

# Addressing the Challenge: Breeding for Organic

OREI has invested more than \$50 million in plant breeding endeavors on certified organic land including:

- Northern Organic Vegetable Improvement Collaborative (2010-current)
- Carrot Improvement for Organic Agriculture (2011-current)
- Tomato Organic Management and Improvement (2014-current)
- Corn – several projects on field, sweet, and specialty corn (2010-current)
- Quinoa (2012-21), rice (2015-current), barley (2017-current)
- Cotton (2010-current)
- Several other crops

## Challenge #2:

# Cultivar choices are limited and often not suitable for organic

- Seed industry consolidation has degraded crop genetic diversity. Many heirloom and regionally adapted cultivars have been lost.
- Breeders at private corporations focus on “large” targets: corn, wheat, soy, etc.
- “Minor” and specialty crops have received less attention from plant breeders.
- Corn, soy, cotton, and canola seeds are mostly GMO, which are not allowed for organic production.



*A green-kernel flour corn (left) and 'Tennessee Red Cob' dent corn (right) offer excellent flavor and have market potential, yet seeds are not widely available.*

# Addressing the Challenge: Farmer-Participatory Plant Breeding

- Farmers and scientists collaborate to identify priorities, evaluate breeding lines, develop and release new cultivars.
- Select for multiple priorities, not single traits.
- OREI funds participatory plant breeding endeavors for vegetables, grains, dry beans, and other crops.
  - Scientists consider farmers essential partners in these projects.
  - Collaborative Plant Breeding Network for Upper Midwest – 6 webinars on organic plant breeding for farmers, students, and other independent breeders.
- Dozens of farmer-bred cultivars now in seed catalogs.



*'Kentucky Rainbow' dent corn in on-farm trial conducted by Common Wealth Seeds in Virginia*

## Resource:

Organic Seed Alliance <https://seedalliance.org/>

- Education, research and advocacy to advance organic seed
- Information, training, and technical assistance for:
  - Farmer-participatory plant breeding and cultivar evaluation
  - Organic production of crop seeds
  - Sourcing best cultivars and certified organic seeds
  - Variety conservation and seed saving
- Major partner in OREI-funded plant breeding projects
- Biennial Organic Seed Growers' Conference, next conference 2024
- Organic Seed Commons online networking platform
- Report: *State of Organic Seed 2022*

## Challenge #3:

# Public plant breeders are an “endangered species”

- Diminished funding for university and USDA public plant breeding and cultivar development programs.
- Steep decline in numbers of University and other public plant breeders; retiring plant breeders are not replaced.
- Non-profits, small seed companies, and independent farmer-breeders working with limited resources struggle to meet the need.
- Urgent need to recruit, train, and establish the next generation of plant breeders, especially for organic.



*Researcher at the Organic Seed Alliance hand-pollinates kale.*

Organic Seed Alliance

# Addressing the Challenge: Training Organic Plant Breeders

## **2016 Student Organic Seed Symposium (SOSS) at U Wisconsin.**

- 3-day conference, farm tours, seed exchange, networking.
- Grad students, LGU faculty, reps from seed companies, NGOs.
- Student breeders sent seeds to Johnny's Seed to grow out prior to the event.
- Six student participants plan 2017 SOSS in Davis, CA.

## **2020 SOSS, Organic Seed Alliance and West Virginia U.**

- Build long term network.
- Regional (WV) seed initiatives – okra, collards, southern peas, corn

## **Student Collaborative Organic Plant Breeding Education (2015-current):**

- Develop crop cultivars for organic
- Provide experiential training for undergraduate and graduate students in organic plant breeding

# Student Collaborative Organic Plant Breeding Education (SCOPE)

U California Davis students work closely with local farmers and faculty plant breeders to develop improved cultivars for organic production in northern CA:

- Field-based classical plant breeding methods
- Common bean – six new releases.
- Pepper – two new cultivars to be released soon.
- Tomato, lima bean, wheat, and zinnia in progress.
- Excellent opportunity for farmers to engage in PBB.
- Collaborating with Organic Seed Alliance.

<https://plantbreeding.ucdavis.edu/scope-project>.



*SCOPE has released six new dry bean cultivars with heirloom flavor and color, disease resistance, and high organic yields.*

## Challenge #4:

### Intellectual Property Rights: Seed Patenting

- Limits or revokes farmers' rights to save, select, and adapt crop seed.
- Restricts plant breeders' access to valuable germplasm.
- Slows progress in development of new cultivars to meet emerging needs.
- Utility patents on crop seeds have impacted:
  - Nearly all cultivars developed through genetic engineering.
  - Some non-GMO cultivars.
  - Some naturally occurring plant genetic traits.
  - Seeds and land races appropriated from Indigenous cultures worldwide.

# Addressing the Challenge: Open Source Seed Initiative (OSSI)

*“You have the freedom to use these OSSI-pledged seeds in any way you choose. In return, you pledge not to restrict others’ use of these seeds or their derivatives by patents or other means, and to include this Pledge with any transfer of these seeds or their derivatives.”*

Concern:

- May limit plant breeders’ compensation for their long years of dedicated work developing cultivars.
- May thereby hinder cutting-edge plant breeding for organic systems.



*“I wish my work to be shared, not monopolized.”*

Frank Morton, lettuce breeder for Fedco Seeds

# Addressing the Challenge: Intellectual Property and Plant Breeders' Livelihoods

- License agreements between University or non-profit plant breeders, and buyers.
  - Royalty (e.g., 10%) to support ongoing breeding.
  - Other equitable and mutually agreed arrangements.
- Plant Variety Protection Act (PVPA)
  - Can save seed for on-farm use but not for resale.
  - Can use PVP variety to develop new lines.
- Utility patent (for comparison)
  - On-farm seed saving is prohibited.
  - Germplasm use by researchers or public plant breeders is severely restricted.



*'Abundant Bloomsdale' spinach developed by Organic Seed Alliance's farmer-participatory breeding program*

# Organic Plant Breeding Research

## Vegetable Crops

# Northern Organic Vegetable Improvement Collaborative

- Funded through OREI since 2010.
- Farmer-breeder network hubs in OR, WA, WI, NY.
- Farmer-identified agronomic and market traits.
- NOVIC cultivars available in seed catalogues:
  - Broccoli – ‘Solstice’ and ‘Myers Best’
  - Butternut squash – ‘Honeynut’ and two additional cultivars released in 2018.
  - Tomato – ‘Iron Lady’ and ‘Brandywise’
  - Sweet corn – ‘Who Gets Kissed,’ ‘Tuxana,’ ‘Top Hat’.
- NOVIC also evaluates existing cultivars in field trials to identify those well-suited to organic production.



*This disease-resistant snow pea, ‘Ho Lan Dow,’ was identified in NOVIC on-farm variety trials.*

# NOVIC 3 (OREI funding 2018-2022)

## **Breeding objectives:** good flavor plus:

- Tomato – disease resistance
- Cabbage – cold tolerance
- Winter squash – long storage, powdery mildew resistance
- Red bell pepper – early maturity
- Sweet corn – early, OP sugar-enhanced

## Outreach:

- Workshops, webinars
- Farmer-participatory breeding and variety trials

## **Outcomes:** cultivars in final evaluation:

- Highly downy-mildew-resistant, high yielding cucumber varieties.
- Early sweet peppers.
- Two sweet corn cultivars to be released in 2023-24.
- Disease resistant high tunnel tomatoes.

Refereed journal article reviewing the farmer participatory plant breeding process.

# Carrot Improvement for Organic Agriculture (CIOA)

- Three OREI awards in 2011, 2016, and 2021.
- Farmer participatory breeding across the US to develop new cultivars with:
  - Excellent flavor, range of colors, high nutritional value.
  - Rapid emergence, seedling vigor.
  - Canopy density, weed competitiveness.
  - Resistance to leaf blight, cavity spot, and pest nematodes.
  - Effective interaction with beneficial soil micro-organisms.
- Accessions collected from around the world.
- Several cultivars released including ‘Carnelian’ red carrot through High Mowing Seeds.
- Good progress on nematode and disease resistance.

# CIOA Develops Weed-Competitive, Disease-resistant Carrots

*“Lines that emerged and formed a full canopy earlier than others resulted in the greatest crop yield in the presence of weeds as well as the greatest ability to suppress weeds. [S]election of lines that favor early and full top canopy growth can be used as a low input, integrated weed management tool.”*

Philipp Simon, Carrot Improvement for Organic Agriculture, final report for OREI award 2011-51300-30903

*“Improved carrot varieties with greater tolerance to biotic and abiotic stress will bring broad environmental benefits by reducing the need for off-farm inputs.”*

Philipp Simon, proposal for OREI award 2021-51300-34900



*‘Danvers 126’ carrot (right) forms larger canopy than other cultivars (left) but is prone to Alternaria leaf blight. CIOA has developed breeding lines with large canopy and leaf blight resistance.*

# CIOA 3: Leveraging On-farm and Below-ground Networks

Role of plant genetics in root microbiome functions:

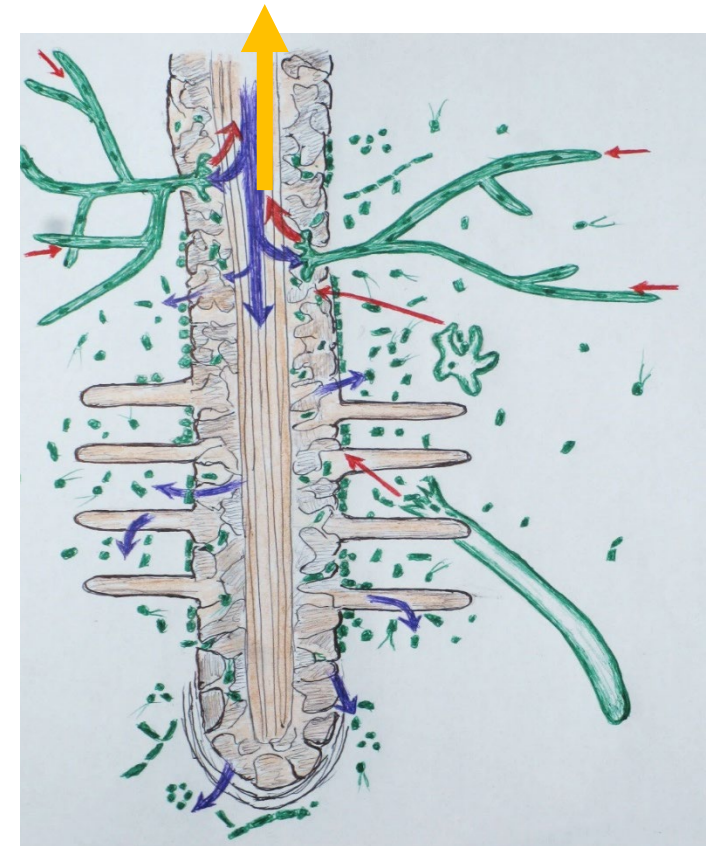
- Suppress pathogens and root knot nematodes
- Induce systemic resistance (ISR) to leaf blight
- Nutrient efficiency, crop growth, yield, and quality
- Reduced uptake of heavy metals in urban gardens

Release more cultivars for organic systems:

- Nematode resistance, flavor, texture, color
- All breeding lines kept in public sector through the Plant Prior Art Repository

Expand farmer-participatory breeding network

- Carrot breeding synergy group, on-farm trials.



Based on diagram by Ray R. Weil

*Crop genetics modulate root exudates (blue) and chemical signals to microbes (green), which assist nutrient uptake (red) and elicit ISR (yellow) that protects the whole plant.*

# Tomato Organic Management and Improvement (TOMI)

Organic IPM for tomato foliar diseases:

- Breeding for resistance to multiple pathogens
- Biofungicides to reduce copper use, protect soil and water
- Cultural practices for beneficial soil microbiome and induced systemic resistance (ISR)

Outcomes of TOMI Part I (2014-18):

- New, multi-disease-resistant varieties with good flavor.
- *Gliocladium* biofungicide as effective as copper.
- The root zone fungus *Trichoderma harzianum* can stimulate plant defenses against foliar diseases (ISR).
- Land races show greater ISR response than modern varieties.



*Late blight (above) can devastate tomato crops. Root association with Trichoderma can protect some tomato land races from late blight and other foliar diseases.*

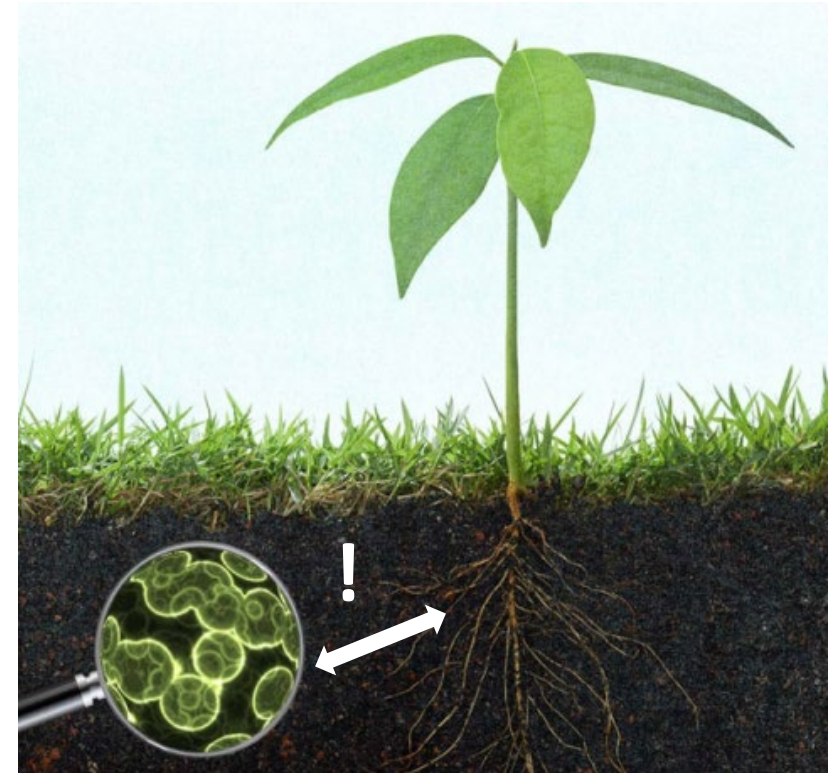
# Tomato Organic Management and Improvement (TOMI) Variety Selection to Restore Plant-Microbe Communication

## TOMI Part II Objectives:

- Continue tomato cultivar development.
- Integrate selection for ISR into breeding program.
- Manage soil health for disease suppression and bio-pesticide efficacy.

## Outcomes:

- Advanced breeding lines with high yield, good flavor, and multi-disease resistance.
- Greater understanding of genetic and epigenetic basis of microbiome and ISR; breeding in progress.
- Studies of compost, soil type, and management impacts on disease suppressiveness underway.



*Crops can be bred to partner more effectively with beneficial soil microbes.*

# Organic Plant Breeding Research

Grains

# Nitrogen-efficient Field Corn

- Traits derived from Latin American land races.
- Requires half as much N as standard hybrids; utilizes organic N sources efficiently.
- N-fixing bacteria in the crop root zone meet up to 50% of crop N need.
- Similar yield, higher protein and methionine content compared to standard hybrids.
- Maintains yield on poor soils.
- Large root system enhances drought tolerance,

Mandaamin Institute, Elkhorn, WI. <http://www.mandaamin.org/>

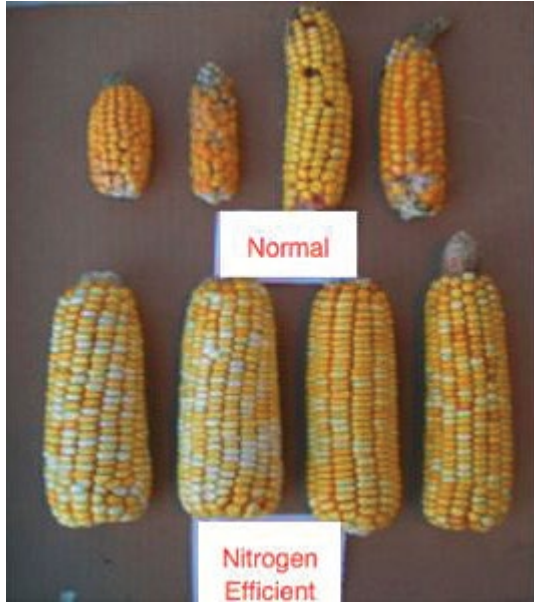


*On low-fertility tropical soil, a Corn Belt hybrid suffers N deficiency (left) while Mandaamin's N-efficient corn maintains vigor (right).*

Mandaamin Institute

# Restoring Beneficial Corn Root Zone Microbiomes

Mandaamin Institute



*Ears from standard (top) and N-efficient (bottom) corn grown on low-N soil*

- Decades of corn breeding in N-fertilized soils have led to:
  - Modified root microbiomes, much less N fixation.
  - Increased N fertilizer needs.
- A few years of seed increase under organic management can improve crop resilience to N limitation.
- An OREI corn breeding project found lower yields in Mandaamin corn than standard hybrids and identified critical root traits:
  - Deeper roots and more fine roots → higher yield.
  - Higher root biomass, more coarse roots → lower yield.

# Meeting a Climate Challenge: Salt-tolerant Rice for Coastal Plain Affected by Sea Level Rise

- Rising sea levels have caused salt intrusion into southeastern coastal plain farmland.
- 300,000 acres of South Carolina rice land impacted.
- Clemson U. plant breeders developing salt tolerant rice:
  - Salt tolerant lines crossed with the region's standard 'Carolina Gold' to initiate cultivar development.
  - Studies on cultivar and salinity impacts on rice-weed competitive dynamics.
  - Soil health and water quality benefits of organic rice production.
  - Trials on six salt-affected organic farms are planned.



Steve Diver, U. Kentucky

*Rice fields are flooded for part or most of the crop's life cycle. When irrigation water becomes saline, yields suffer.*

# Breeding and Agronomy of Quinoa for Organic Systems

## Project goals:

- Farmer-participatory quinoa breeding and variety trials in WA, UT, MN, and MD.
- Select for yield, maturity, regional adaptation, and heat, drought, and pest tolerance.
- Best agronomic practices for organic quinoa in different regions.
- Genotype effects on mycorrhizal, rhizosphere, and endophytic associations.
- Protein content and end-use quality of quinoa cultivars.

## Project Outcomes:

- Over 200 farmer selections from multiple regions.
- Several new quinoa cultivars to be released soon.
- Root microbiome function and nutritional quality of breeding lines documented.

# Organic Plant Breeding Research

Cover Crops

# Breeding Cover Crops for Soil Health

Genetic variability in:

- Seedling emergence, vigor, biomass, root depth.
- N fixation (legumes), nutrient recovery.
- Cold hardiness, drought and heat tolerance.
- Flowering and maturity date.
- Ease of termination by roller-crimper or mower.
- Weed suppressive ability.
- Disease and pest nematode suppression.



*Sudangrass + southern peas (top),  
rye + vetch + winter peas  
(lower left), mustard ( lower right)*

# Examples of Heritable Traits in Cover Crops

## Cold hardiness:

- Fava bean lines hardy to Zone 6b have been developed for use in eastern WA .
- Some hairy vetch strains are hardy in MN.

## Maturity date:

- 'Abruzzi' rye heads 3 weeks before most VNS rye.
- 'Purple Bounty' hairy vetch flowers 2 weeks before most other hairy vetch strains.
- Windy Acres Organic Farm in Tennessee grows these two cultivars together for roll-crimp termination.

(2017 Presentation at Southern SAWG Conference)



*Most fava beans (left) are hardy to 15-20°F. New lines hardy to < 0°F have been developed. Hairy vetch (right) varieties differ in maturity date and response to roll-crimping.*

# Nationwide Cover Crop Breeding Network



- Develop and release improved cover crop cultivars.
  - Hairy vetch, winter pea, and crimson clover breeding initiated in 2015.
  - Nationwide cereal rye breeding launched in 2021.
  - Trials in GA, ID, KS, MD, MN, MO, NC, ND, NE, NY, OR, WA, WI.
  - Emergence, vigor, winter survival, biomass, flowering date, seed yield.
  - Trial in AK in 2022-23 to test survival in extreme winter cold.
  - Disease resistance, weed suppression, soft seed.
- Overcome barriers to cover crop seed production.
- Develop cover crop variety trial database to help farmers choose cover crop cultivars.





**Questions?**

