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

Research-based Practical Guidance for Organic and Transitioning Farmers

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Dawn Thilmany, PhD, *Colorado State University*

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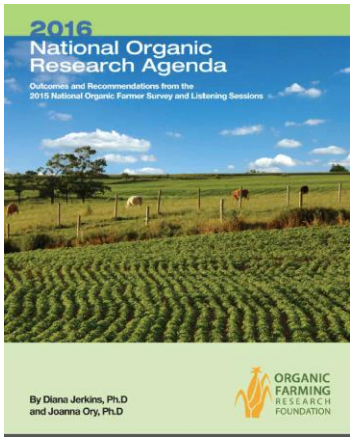
Research Priorities for Western Region Organic Farmers



- Soil health – **71%**
  - Root-soil microbiome interactions and crop health
- Fertility management – **66%**
- Weed management – **63%**
  - Varieties that require less fertility input and compete better with weeds

Report available at: https://ofrf.org/

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Research Priorities for Western Region Organic Farmers

Doug Crabtree

Drought resilience is a critical trait for organic dryland crops like this spelt in Montana.

- Water management– **56%**
  - Designing for drought resistance
- Disease management – **52%**
  - Plant breeding for disease resistance
  - Disease-resistant rootstock for perennial crops

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The Role of Crop Genetics in Soil Health

Direct and Indirect Impacts

Can the Right Cultivars Help Organic Farmers Build Healthy Soils?

Yes, if heritable traits:

- Facilitate profitable organic production.
- Reduce the need for inputs.
- Confer disease and stress resilience.
- Reduce erosion and build soil organic matter and tilth.
- Support beneficial soil life.

'Abundant Bloomsdale' spinach, adapted to the Pacific Northwest, is cold-hardy, slow to bolt, and offers excellent flavor.

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Breeding Crops to Need Fewer Inputs

- Efficiently utilize nutrients from organic sources
  - *Need less fertilizer*
- Utilize water efficiently
  - *Need less irrigation*
- Outcompete, tolerate, or suppress weeds
  - *Need less cultivation*

Sweet corn selected to thrive in organic dry-farm conditions.

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Breeding Crops to Feed and Build Soil

- High biomass
- Closed canopy
- Deep, extensive roots
- Abundant root exudates to feed soil life
- Enhanced association with mycorrhizal fungi and other beneficial soil organisms

Doug Crabtree
Vilicus Farms

These sunflowers add organic matter and feed soil life while providing a valuable oilseed cash crop.

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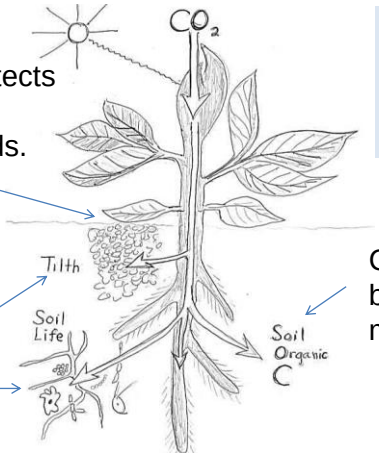
Vigorous, High-biomass Cultivars

Crop canopy protects soil surface and suppresses weeds.



Tradeoff: marketable yield *versus* organic inputs to the soil

Root exudates enhance soil aggregation and feed soil organisms.

Crop residues build soil organic matter (SOM).

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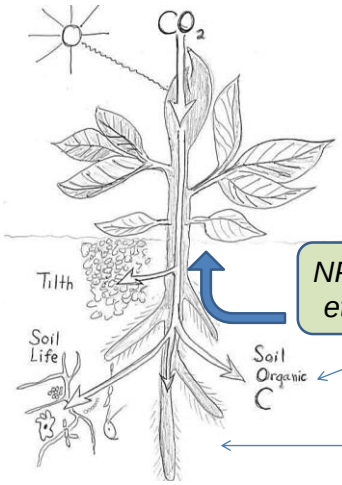
Deep, Extensive Root System



Larger root mass enhances nutrient uptake efficiency

Root residues build active and stable SOM.

Deep roots break hardpan, retrieve nutrients, and access deep moisture.

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Root Depth, Mass, and Architecture as Heritable Traits

Crop cultivars vary in:

- Root depth and lateral spread.
- Root architecture (density and pattern of root branching).
- Root hair density.

Breeding crop varieties for deep, extensive roots can:

- Build SOM.
- Enhance beneficial soil biota.
- Improve nutrient and water use efficiency.

Italian ryegrass

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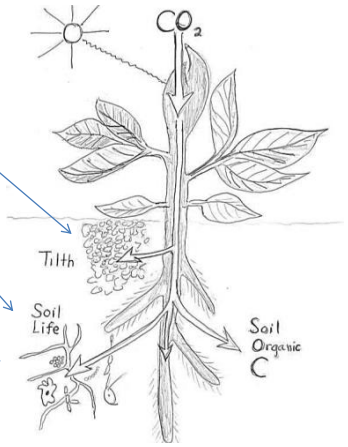
Effective Teamwork with Soil Microbes

Enhanced quantity and quality of root exudates

Specific chemical signals to beneficial soil organisms

Enhanced root microbiome:
- N fixers
- Mycorrhizae
- Disease antagonists
- Other



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The Role of Crop Genetics in Soil Health

A Few Research Examples

Nitrogen-efficient Field Corn

- Thrives on organic N.
- Hosts N fixing bacteria and other beneficial soil life.
- Saves money on fertilizer.
- Produces similar yields compared to conventional hybrids.
- Has higher percent protein and quality.
- Maintains yield on poor soils.
- Tolerates drought well.

Mandaamin Institute

On low-fertility soil, a Corn Belt hybrid suffers N deficiency (left) while N-efficient corn maintains vigor and yield (right).

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

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Growing Tomatoes on Less Water

- OFRF-funded study shows reduced irrigation need in healthy soil.
- Some farmers “dry-farm” tomato to improve flavor and cut costs.
  - Less irrigation reduces ponding and N leaching.
- Early Girl and New Girl (Johnny’s) are best for dry farming.
  - Deep, extensive roots access subsoil moisture.

Tomato cultivars vary widely in drought tolerance, as shown in this dry-farmed variety trial in CA.

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Breeding Drought Resilient Grains

Washington State University

- Hulless barley, quinoa, and other specialty grains
- Drought, weed, and disease resistance

International breeding programs select for drought resistance:

- Cereals, corn, rice, and beans
- Selected in "managed stress nurseries"

Rainbow quinoa selected by California farmer Blake Richard to tolerate high density seeding in organic dry-farm conditions.

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Carrot Improvement for Organic Agriculture (CIOA)

- Breeding objectives:
  - Early emergence and seedling vigor
  - Canopy height and density for weed suppression
  - Resistance to leaf blight and pest nematodes
  - Beneficial interaction with soil micro-organisms
  - Flavor, nutritional value
- Farmer participatory breeding in CA, WA, IN, and WI
- Funded through USDA Organic Research and Extension Initiative (OREI)

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Weed-Competitive Carrots

CIOA is developing carrot cultivars with large canopies, good blight resistance, and great flavor.

"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, CIOA final report for OREI 2011-01962, http://cris.nifa.usda.gov/

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Genetics of Plant-Soil-Microbe Partnerships in Carrots

CIOA project has identified genetic variability in:

- Ability to host rhizosphere and endophytic (within root tissue) microbes that:
  - Protect against *Alternaria dauci* leaf blight.
  - Enhance nutrient uptake and crop growth.
- Efficacy and species-specificity of association with arbuscular mycorrhizal fungi (AMF) to:
  - Enhance nutrient uptake.
  - Improve drought and flood resilience.

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Tomato Organic Management and Improvement (TOMI)

Organic tomato disease IPM including:

- Breeding for multiple disease resistance
- Induced systemic resistance (ISR)
- Bio-fungicides—microbial antagonists
- Limited use of copper

Genetic regulation of:

- Tomato nutrient use efficiency
- Exclusion of toxic heavy metals from urban soils

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Induced Systemic Resistance (ISR)

- *Trichoderma harzianum* fungi in root zone stimulate plant defenses
- ISR can protect the crop against several major foliar diseases.
- Land races show greater ISR and growth response to *T. harzianum* than modern varieties.
- Breeding goal: introduce ISR trait into modern tomato cultivars

ISR protects some, but not all, tomato cultivars from late blight (above) and gray mold.

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Tightly Coupled N Cycling in Organic Tomato in CA

Three nutrient cycling patterns:

- *N deficient* – low soluble N, low yield
- *N saturated* – high soluble N, high yield, and high N leaching risk
- *Tight N cycling* – low soluble N, high yield with minimal N leaching risk

N cycling regulated by:

- Soil life and SOM
- Plant enzymes under genetic control

Bowles et al., 2015. Plos One.

Vigorous tomatoes grown on moderate C:N compost and no concentrated N.

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Breeding Cover Crops for Soil Health

Genetic variability in:

- Vigor, biomass
- N fixation (legumes)
- Cold hardiness
- Flowering date
- Ease of termination
- Weed suppression
- Disease and pest nematode suppression
- Water use efficiency

Provided by NCAT / ATTRA

Photo shows high biomass oats + vetch cover in Pacific Northwest. Better cold hardiness and N fixation could benefit farmers.

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Hardiness and Maturity Date

Bell bean (small-seeded fava)

- New lines hardy to zone 6B in eastern WA

Hairy vetch

- Farm-saved seed hardy in MN
- Purple Bounty matures two weeks early, easier to roll-crimp

Winter rye

- Abruzzi matures three weeks early

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Breeding Hairy Vetch, Crimson Clover, and Austrian Winter Pea for Organic Systems

<u>Project objectives</u>

- N fixation
- Winter hardiness
- Biomass
- Early vigor
- Weed suppression
- Regionally adapted cultivars
- Long-term endeavor

<u>Project methods</u>

- Research station and on-farm trials in all four USDA regions
- Farmer participatory breeding and evaluation
- NRCS plant materials centers in nine states
- Seed increase in WA, TX

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Challenges in Finding the Best Crop Cultivars …

… to Build Healthy Soil
and Make a Living Organically.

Challenge #1: Modern Varieties 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 varieties require >200 lb N/ac for optimum yield. Half of this N is lost to leaching or denitrification.

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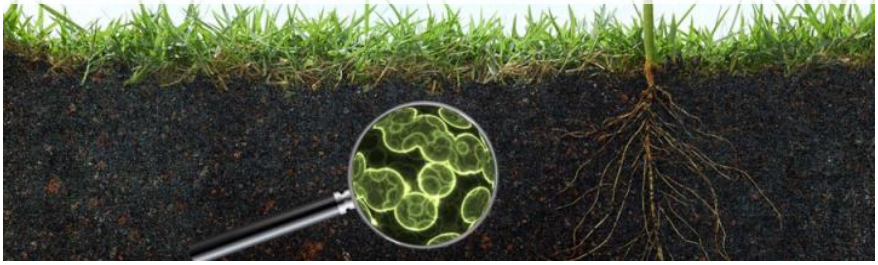
Have Modern Cultivars Forgotten How to "Talk" with Soil Life?

- Growing crops in NPK-saturated, conventional fields can put mycorrhizal fungi, N fixers, and other valuable microbes out of work.
- Breeding and selecting crops in such systems can create cultivars that don't "invite" these helpers into their root zones.



Challenge #2: Cultivar Choices are Limited and Not Adapted to Locale

- Seed industry consolidation results in loss of regionally adapted cultivars.
- For-profit private breeders focus on commodity crops.
- "Minor" or specialty crops receive less attention.
- Corn, soy, cotton, and canola seeds are mostly GMO, not suited for organic production.

An unusual flour corn that is not widely available.

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Farmer Frustration with Organic Seed

- "[Organic] seed is very expensive … plus the quality is often inferior … if there were cultivars developed specifically to thrive under organic … the additional cost would be offset by increased productivity."
- "Most companies aren't interested in developing drought resistant varieties with characteristics … for organic."
- "The genetics are horrible - conventional non-treated, non-GMO always out yields organic hybrids."
- "Short wheat, short root systems, lower protein … higher N needs are really not what we need."

Farmer quotes, 2016 NORA, pp 105-7, https://ofrf.org/

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Challenge #3: Public Plant Breeders are an Endangered Species

- Diminished funding for public plant breeding and cultivar development
- Steep decline in numbers of university and other public plant breeders
- Urgent need to recruit, train, and establish the next generation of plant breeders

Organic Seed Alliance

Researcher from Organic Seed Alliance pollinating kale. The private non-profit sector aims to develop new cultivars for 21st century producers.

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Challenge #4: Intellectual Property and Farmers' Rights

Open Source Seed Initiative (OSSI).

- Users are free to grow, share, sell, or trial and study OSSI seed, and use it to breed new lines.
- Any new variety developed from OSSI germplasm must remain Open Source.

Eric Brennan, Salinas Organic Cropping Systems Trial

"I wish my work to be shared, not monopolized." Frank Morton, lettuce breeder for Fedco Seeds

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Challenge #4: Intellectual Property and Farmers' Rights

- License agreements between university or non-profit plant breeders, and vendors and end users of seed
  - Royalty (e.g., 10%) to support ongoing breeding
- 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
  - On-farm seed saving prohibited
  - Germplasm use by researchers severely restricted

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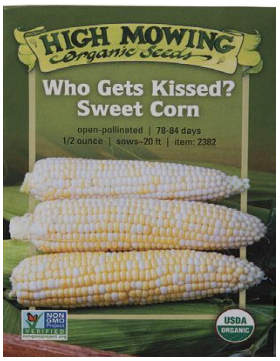
Meeting the Challenges

Working Together to Develop Seeds for Healthy Soils and Healthy Organic Farm Profits

Farmer Participatory Plant Breeding (PPB)

- Farmers work with scientists to set priorities, evaluate breeding lines, and develop and release new cultivars.
- USDA Organic Research and Extension Initiative (OREI) funds PPB endeavors for vegetables and field crops.
- Select for multiple priorities, not focused on single traits



Who Gets Kissed? sweet corn developed through on-farm trials

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Northern Organic Vegetable Improvement Collaborative (NOVIC)

- Funded through OREI since 2010
- Farmer-breeder network hubs in OR, WA, WI, and NY
- NOVIC cultivars available in seed catalogues:
  - Broccoli – Solstice and Myers Best
  - Butternut squash – Honeynut and two new lines 661 and 898 released in 2018
  - Tomato – Iron Lady and Brandywise
  - Sweet corn – Who Gets Kissed, Tuxana, Top Hat
- More on the way

https://seedalliance.org/tag/northern-organic-vegetable-improvement-collaborative-novic/

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Student Collaborative Organic Plant Breeding Education (SCOPE)

UC Davis students and faculty work with local farmers to develop cultivars for organic production:

- Field-based classical plant breeding
- Seven common bean cultivars ready for testing by seed vendors and producers
- Also breeding tomato, pepper, and lima bean
- Expanding into new crops and regions
- Excellent opportunity for farmers to engage in PPB
- Collaborating with Organic Seed Alliance

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

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PPB Researcher Enthusiasm and Practical Challenges

"More than 70% of the organic seed research projects conducted … 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

Challenges in PPB:

- Farmers must acquire new skills.
- Farmers must receive sufficient compensation for the work.
- Cultivar development takes 4 – 10 years, plus 2 – 4 years to bring a new cultivar to market.

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Tips for Finding the Seeds you Need

Selecting Cultivars for Soil Health, and Performance in Organic Systems

Making the Best Use of What is Available

- Seek locally produced seed.
- Choose cultivars bred in and for organic systems.
- Select regionally adapted varieties that:
  - Emerge and establish rapidly.
  - Compete with weeds.
  - Resist major diseases and pests in your region.
  - Utilize nutrients from organic sources efficiently.
  - Tolerate drought and other stresses.
- Conduct on-farm variety comparisons.

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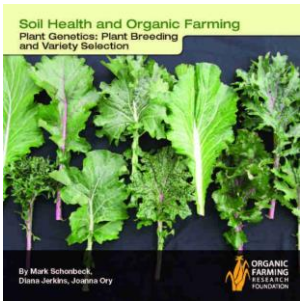
Sourcing and Choosing Organic Seed

- Directory of Organic Seed Suppliers, updated Aug. 2018 https://attra.ncat.org/attra-pub/organic_seed/
- Organic Seed Alliance http://www.seedalliance.org/
- Some vendors provide detailed information on cultivar traits:
  - Blue River Organic Seed



This OFRF Guide lists organic seed sources by region.

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Get Involved: Breed and Grow Better Seeds for Organic Farms

- Learn organic seed production, cultivar evaluation, and plant breeding skills.
- Save and select seed from favorite cultivars. *Use non-patented seed—OSSI or local is best; PVP is OK.*
- Participate in local seed swaps and conservation groups like Seed Savers Exchange, https://www.seedsavers.org.
- Contract with a local seed company to grow organic seed or evaluate breeding lines.
- Participate in farmer-participatory plant breeding.

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Resources for Participatory Plant Breeding and Seed Production

Organic Seed Alliance (OSA)
http://www.seedalliance.org/

- Manuals and workshops on seed production and breeding
- Variety trial information
- Proceedings of Organic Seed Growers Conferences
- Technical support for farmer-led breeding projects
- Breeding populations for additional on-farm selection

Organic Seed Alliance

OSA farmer participatory spinach breeding project developed Abundant Bloomsdale, a variety adapted to the Pacific Northwest.

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Resources for Participatory Plant Breeding and Seed Production

- **The Experimental Farm Network**, http://experimentalfarmnetwork.org/
  - Open source network
  - Upland rice, perennial grains and beans, etc.
- **SCOPE** (UC Davis), **NOVIC, TOMI, CIOA,** etc.
  - Contact Jared Zystro of OSA, jared@seedalliance.org
- **Kevin Murphy, Washington State University** http://css.wsu.edu/people/faculty/kevin-murphy/
  - PPB in barley, quinoa, spelt, and other specialty grains

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Seed Companies with PPB Programs

- **Wild Garden Seed**. Willamette Valley, OR. Vegetables, flowers, and herbs. https://www.wildgardenseed.com/.
- **Siskiyou Seeds**. Vegetables, grains, flowers, and herbs. https://www.siskiyouseeds.com/collections/grains.
- **Adaptive Seeds**. Vegetables, flowers, herbs, and grains. https://www.adaptiveseeds.com/.
- **Lupine Knoll Farm**. http://www.lupineknollfarm.com/.
- **Fertile Valley Seeds**. Carol Deppe, plant breeder. Dry beans, corn, and vegetables. http://www.caroldeppe.com/.

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Recent Developments in Public Plant Breeding for Organic

Research Funding and Cultivars in the Pipeline

USDA Funds Plant Breeding for Organic

"Strengthen organic crop seed systems, including … plant breeding for organic production, with an emphasis on publicly available releases. Goals … can include, but are not limited to: disease, weed, and pest resistance; stress tolerance; nutrient use efficiency; performance in soil-improving and climate-friendly systems such as organic no-till; quality and yield improvement; and … cover crop breeding for enhanced performance in organic systems."

USDA Organic Research and Extension Initiative, 2018 Request for Applications, Priority 4 (p 5).

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OREI Program News

2018 OREI Awards include:

- NOVIC 3 – continue PPB in sweet corn, tomato, cabbage, pepper, cucumber, and winter squash
- Cover crop breeding – continued funding for Mirsky and colleagues at USDA ARS in Beltsville, MD

OREI's future:

- 2018 Farm Bill grants permanent funding
- 2019 RFA due May 2, 2019
- 2020 RFA due January 23, 2020

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Looking into the Near Future

Some promising cultivars in the pipeline include:

- Tomatoes resistant to seven major diseases (TOMI)
- Improved red and purple carrots (CIOA)
- Carrot breeding stock resistant to two pest nematodes (CIOA).
- Several new sweet corn varieties, one specifically adapted to the Olympic Peninsula (NOVIC)
- New varieties of red cabbage, pepper, delicata squash, tomato, and snow and snap peas (NOVIC)

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Questions?