Microbe-containing Biostimulants: Current Issues and Future Prospects

National Association of Independent Crop Consultants
January 18, 2019; Savannah, GA

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Extension Specialist

THE OHIO STATE UNIVERSITY
COLLEGE OF FOOD, AGRICULTURAL, AND ENVIRONMENTAL SCIENCES

Today's Topics

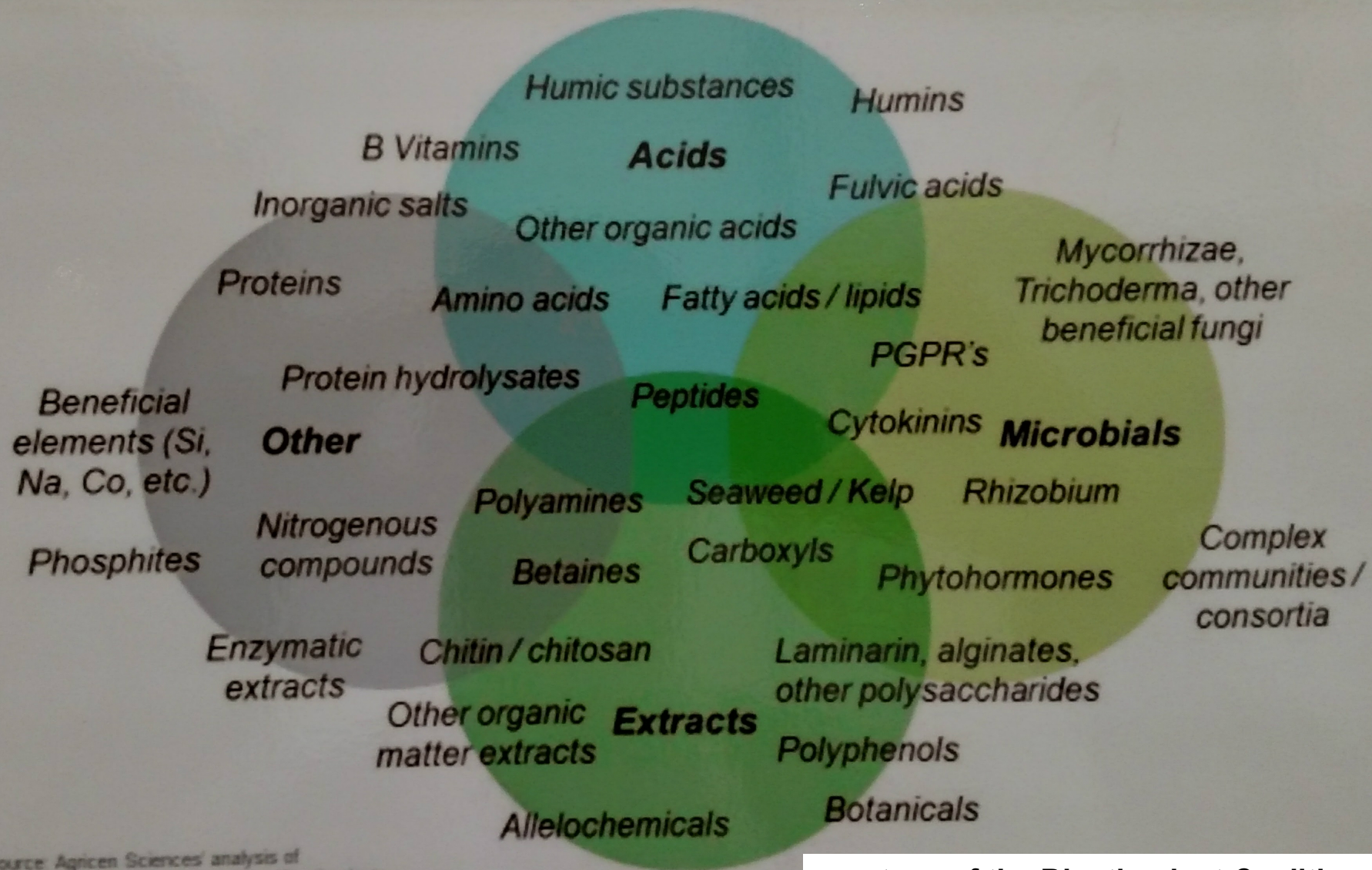
- impacts? (consistent, statistically significant)
- biostimulant science
- place in toolbox

Current U.S. House Farm Bill Language (in markup)*…

"plant biostimulant" means a substance or micro-organism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield.

*courtesy of David Beaudreau, The Biostimulant Coalition

The Emerging Landscape of Products – Broad and (Potentially) Confusing



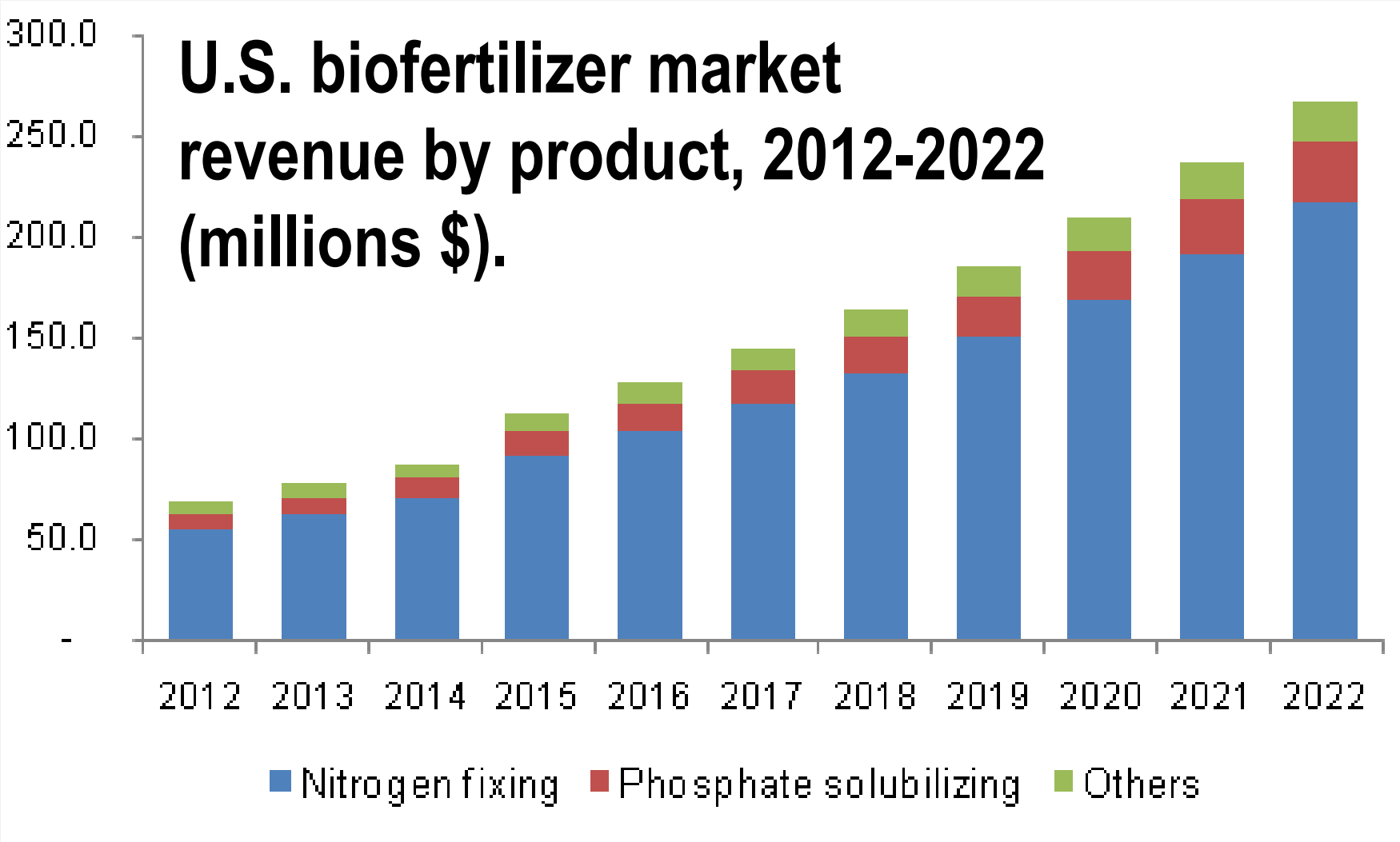
Source: Agricen Sciences' analysis of market analysts, survey papers on Biostimulants

courtesy of the Biostimulant Coalition

Biostimulant Organizations

- Biological Products Industry Alliance https://www.bpia.org/
- Biostimulant Coalition http://www.biostimulantcoalition.org/

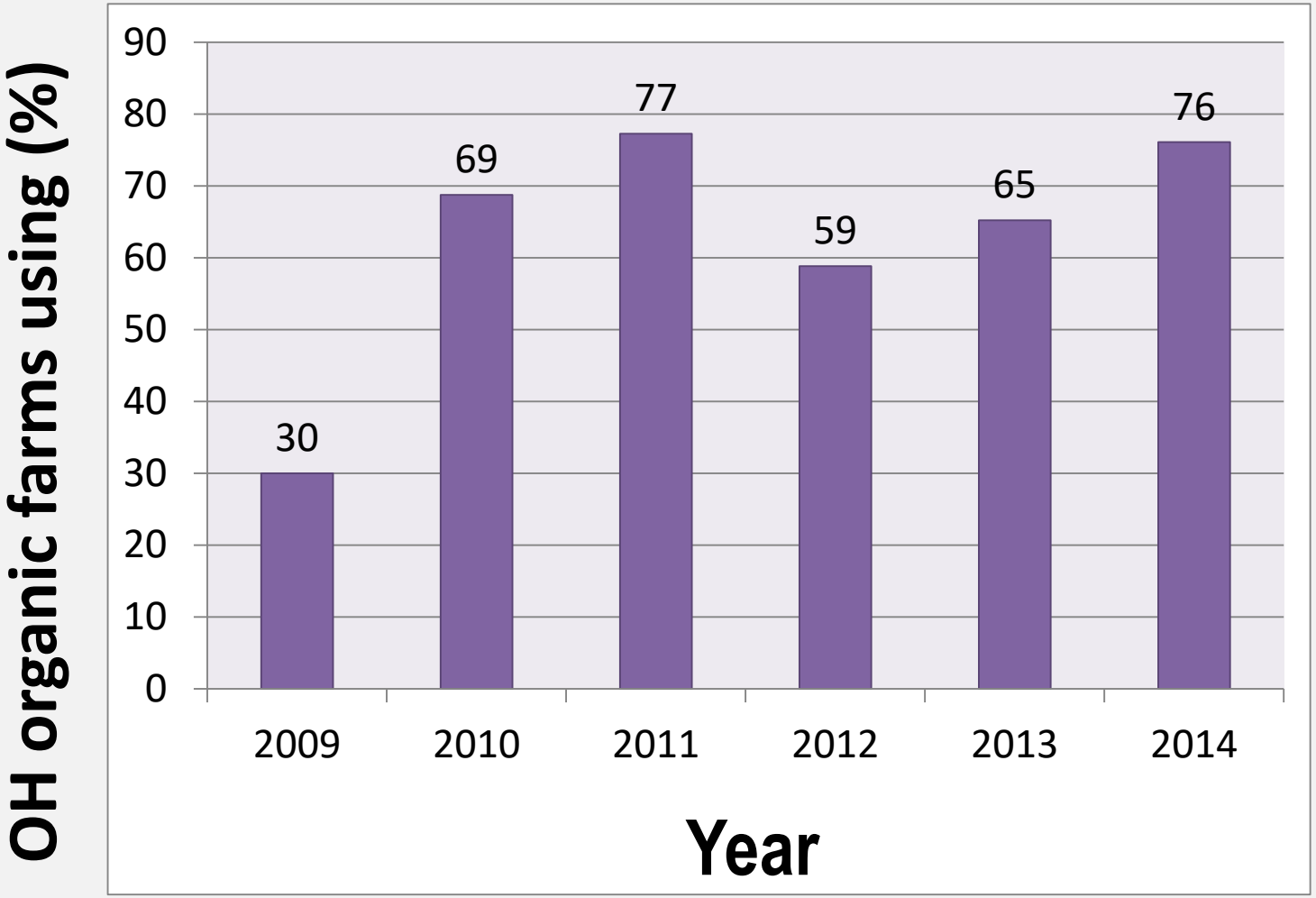
Microbe-containing Biostimulants



Source: http://www.grandviewresearch.com/industry-analysis/biofertilizers-industry

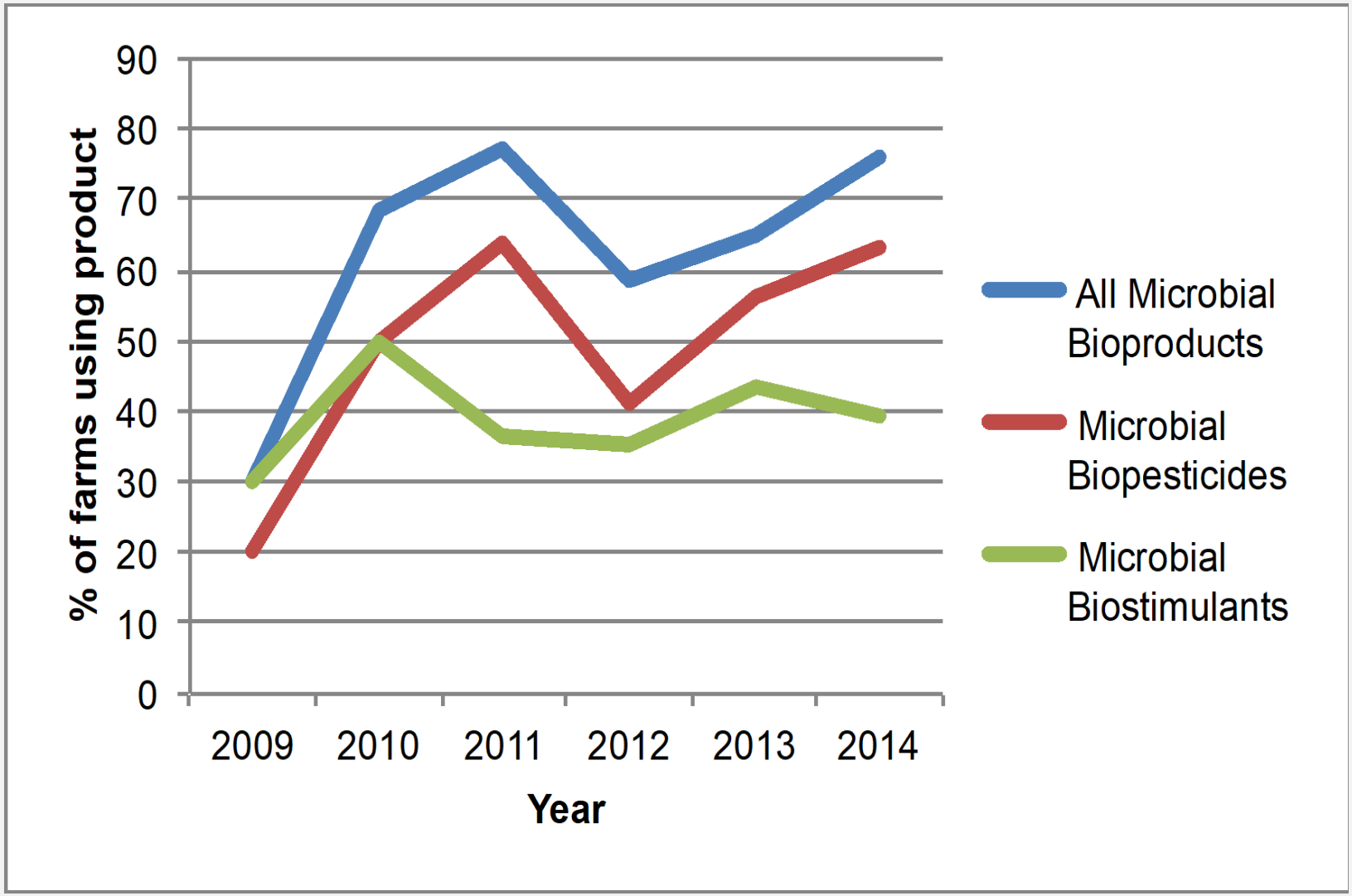
Global biofertilizer market worth 2.31 Billion USD by 2022.

Biopesticide and Biofertilizer Use over Time*



Laudick, J. et al. 2016. M.S. Thesis, The Ohio State Univ.; Microbial biostimulants in organic farming systems: patterns of current use and an investigation of their efficacy in different soil environments.

* Together, these products accounted for 9% by number of all inputs on these farms (412 distinct types inputs classified into 14 categories).



Data were collected from organic certification records of vegetable producers submitted to the Ohio Ecological Food and Farming Association between 2009-2014.

Microbial biopesticide use has increased, whereas microbial biostimulant use has fluctuated around 40%.

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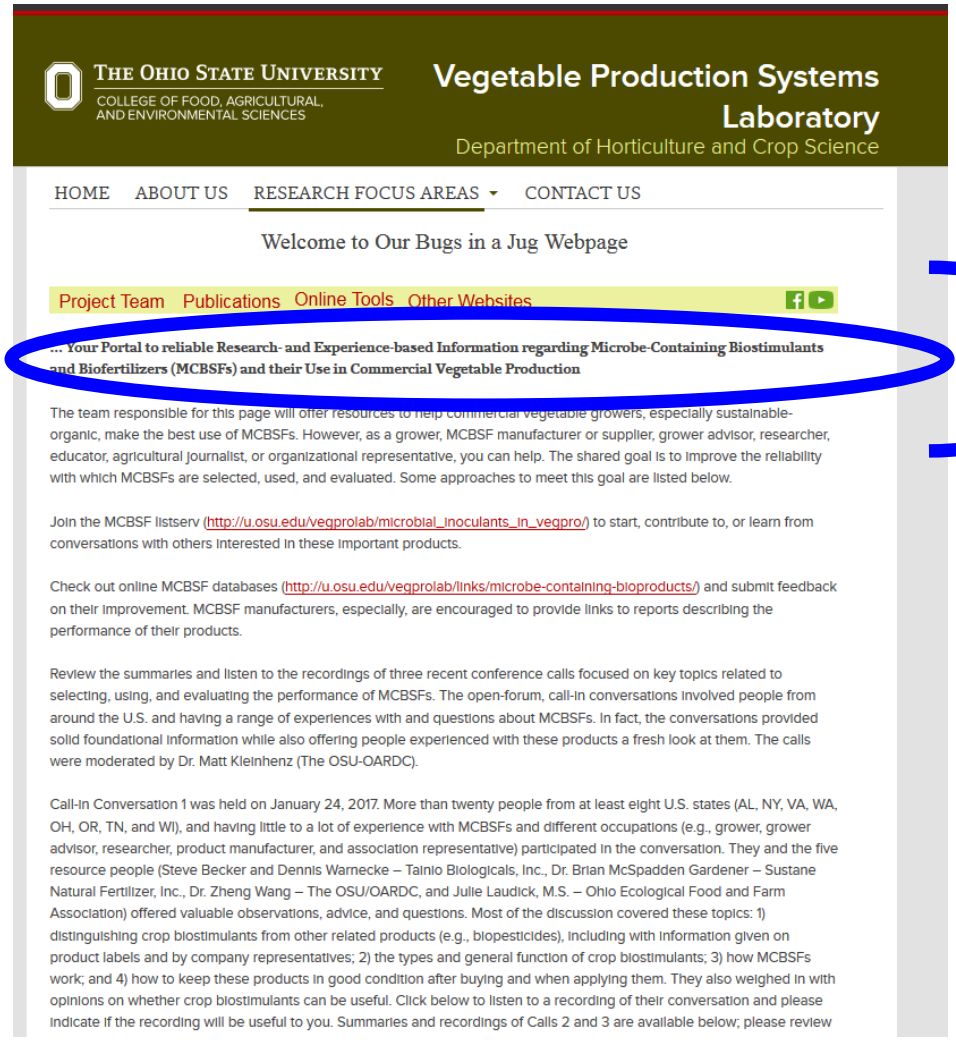
- https://www.acsmeetings.org/
- https://ashs.org
- http://www.apsnet.org/
- Organic Agriculture Research Forum
- many grower-/consultant-oriented technical programs



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... Your Portal to reliable Research- and Experience-based Information regarding Microbe-Containing Biostimulants and Biofertilizers (MCBSFs) and their Use in Commercial Vegetable Production

The team responsible for this page will offer resources to help commercial vegetable growers, especially sustainable-organic, make the best use of MCBSFs. However, as a grower, MCBSF manufacturer or supplier, grower advisor, researcher, educator, agricultural journalist, or organizational representative, you can help. The shared goal is to improve the reliability with which MCBSFs are selected, used, and evaluated. Some approaches to meet this goal are listed below.

Join the MCBSF listserv (http://u.osu.edu/vegprolab/microbial_inoculants_in_vegpro/) to start, contribute to, or learn from conversations with others interested in these important products.

Check out online MCBSF databases (http://u.osu.edu/vegprolab/links/microbe-containing-bioproducts/) and submit feedback on their improvement. MCBSF manufacturers, especially, are encouraged to provide links to reports describing the performance of their products.

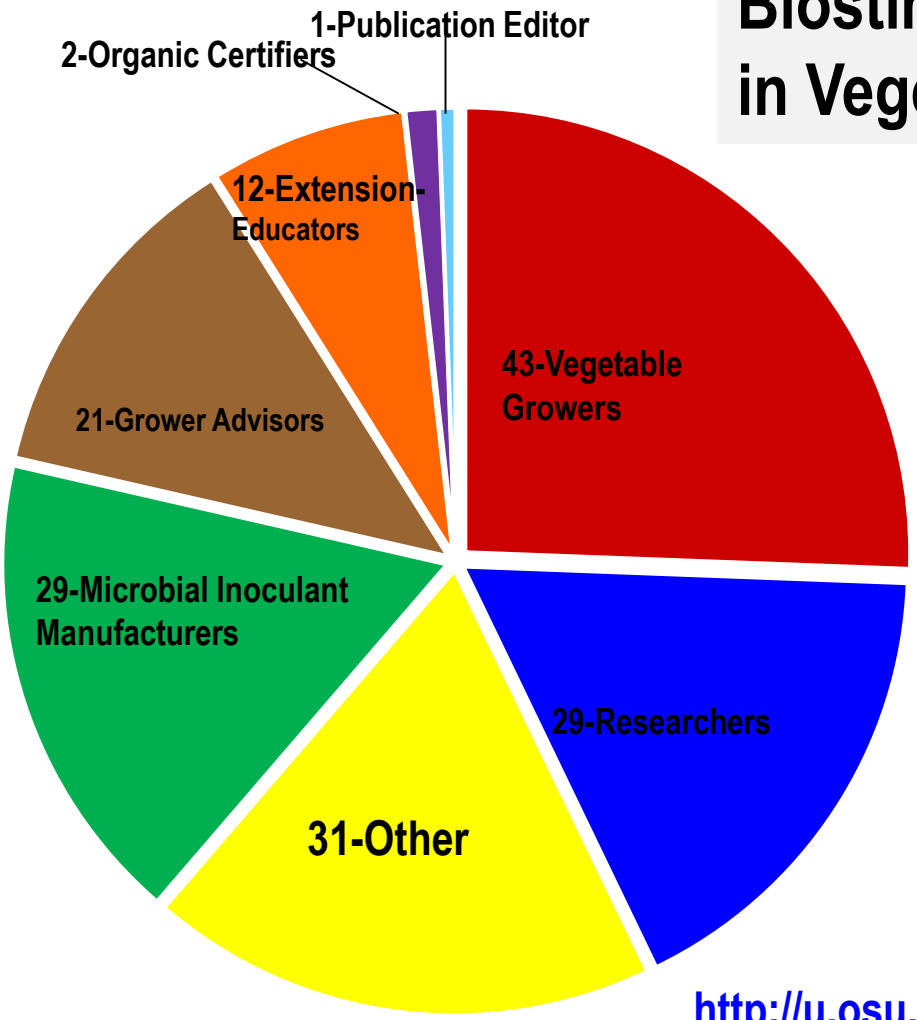
Review the summaries and listen to the recordings of three recent conference calls focused on key topics related to selecting, using, and evaluating the performance of MCBSFs. The open-forum, call-in conversations involved people from around the U.S. and having a range of experiences with and questions about MCBSFs. In fact, the conversations provided solid foundational information while also offering people experienced with these products a fresh look at them. The calls were moderated by Dr. Matt Kleinhenz (The OSU-OARDC).

Call-in Conversation 1 was held on January 24, 2017. More than twenty people from at least eight U.S. states (AL, NY, VA, WA, OH, OR, TN, and WI), and having little to a lot of experience with MCBSFs and different occupations (e.g., grower, grower advisor, researcher, product manufacturer, and association representative) participated in the conversation. They and the five resource people (Steve Becker and Dennis Warnecke – Tainio Biologicals, Inc., Dr. Brian McSpadden Gardener – Sustane Natural Fertilizer, Inc., Dr. Zheng Wang – The OSU/OARDC, and Julie Laudick, M.S. – Ohio Ecological Food and Farm Association) offered valuable observations, advice, and questions. Most of the discussion covered these topics: 1) distinguishing crop biostimulants from other related products (e.g., biopesticides), including with information given on product labels and by company representatives; 2) the types and general function of crop biostimulants; 3) how MCBSFs work; and 4) how to keep these products in good condition after buying and when applying them. They also weighed in with opinions on whether crop biostimulants can be useful. Click below to listen to a recording of their conversation and please indicate if the recording will be useful to you. Summaries and recordings of Calls 2 and 3 are available below; please review

... "portal to research- and experience-based information regarding microbe-containing biostimulants and biofertilizers (MCBSFs) and their use in commercial vegetable production."

http://u.osu.edu/vegprolab/research-areas/vegebiostimsferts/

Microbial Biostimulants/Biofertilizers in Vegetable Production ListServ



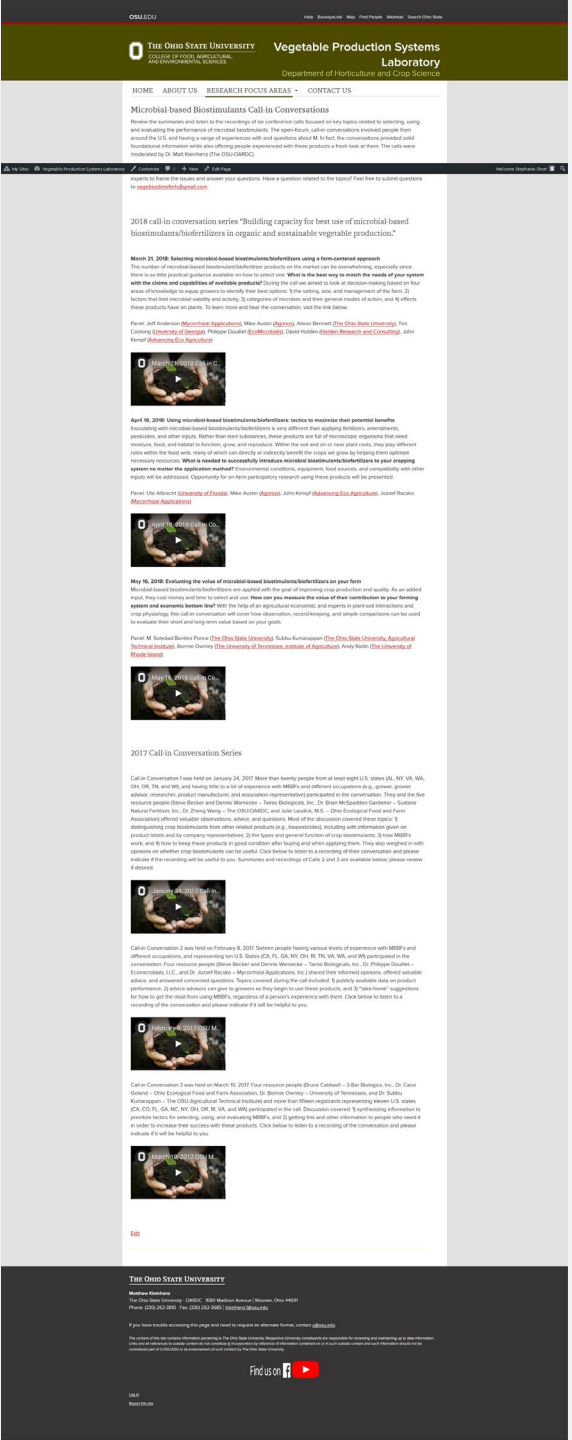
- to our knowledge, the first listserv to focus on MCBSFs
- launched in April 2016; now with 168 members
- email forum; ask questions, share info on MCBSFs

http://u.osu.edu/vegprolab/microbial_inoculants_in_vegpro/

updated 2-28-18

Conference Call Participants

	Total #	List
people	184	
states represented	27	AL, AZ, CA, CO, CT, DC, FL, GA, HI, IA, IL, IN, KY, MA, MI, NC, ND, NV, NY, OH, OR, RI, SD, TN, VA, WA, WI
affiliations		farm, university, organization, product manufacturing/supply
experience with MCBSs		none to extensive



Discussions recorded, available for listening.

https://youtu.be/XZscnl05RyI

https://youtu.be/hwiMtasdRWk

https://youtu.be/HKS0Qvu05mA

https://youtu.be/2zKC3ppSOUg

https://youtu.be/6xu28f2eNB0

https://youtu.be/Vpf5cDPt110

Presentations at grower and industry programs in FL, IN, OH, IL, NY, NC, CA, KY, and Ontario coordinated by universities and/or grower associations (10/17 – 12/18).

Field Days – Summer 2017

Microbial-based Biostimulants: Big Potential in Small Packages | Growing Produce - Mozilla Firefox

www.growingproduce.com/vegetables/microbial-based-biostimulants-should-you-use-them-in-your-production/

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Trending Now: #Biostimulants

Forecasters Subtract another Slice from Florida Citrus | Florida Growers Explore New Solutions to Age-Old Problems

November 13, 2017

Microbial-based Biostimulants: Big Potential in Small Packages

By: Matt Kleinhenz | Email

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There is no shortage of interest in or questions and opinions about biostimulants. Many are working to develop them as key tools in grower toolboxes and to help growers use them effectively. One part of the effort is focused on identifying microbes that enhance crop growth under a range of conditions, including ones that ordinarily reduce yield (e.g., low soil moisture and/or fertility). The other part focuses on identifying methods that allow plant-microbe interactions to be most useful to growers.

Why the fuss? The science is promising. Years of experiments in controlled environments suggest that the potential upside in production will be real, i.e., that inoculated crops will outperform non-inoculated ones. While some are already convinced, others need more proof collected on farms and in more 'real-world' situations. They also point to the dozens of products and the lack of information about them and see a need to create grower-friendly resources similar to ones available for biopesticides. It can be difficult to know when or even, if, a biostimulant is working. So, reliable protocols for assessing their effects in field and high tunnel systems are needed.

Discussion helps and there is plenty taking place. I have been fortunate to hear from many growers, suppliers, grower advisors, and researchers regarding their views on biostimulants, especially as we discuss the current situation and steps that may help more growers obtain greater value from their investments in biostimulants. Some of the comments shared most often are summarized below.

Grower Perspectives on Microbial-based Biostimulants

- They can't hurt and they may help … they act as insurance
- Their (low) cost makes their possible upside appealing
- Everyone can't be wrong. Popularity = efficacy
- I hear good things about beneficial microbes and their effects on crops and farms. I want to promote soil life but it's

The Latest

Biocontrols Conferen… November 13, 2017 Biostimulants Making Big Strides as It S…

Biocontrols Conferen… November 13, 2017 So What Exactly Are Biostimulants, Anywa…

Biocontrols Conferen… November 13, 2017 Microbial-based Biostimulants: Big Poten…

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Citrus September 11, 2017 The Grower's Take: Citrus, HLB, and Biol…

Biocontrols Conferen… September 1, 2017 Dispelling the Rumors:

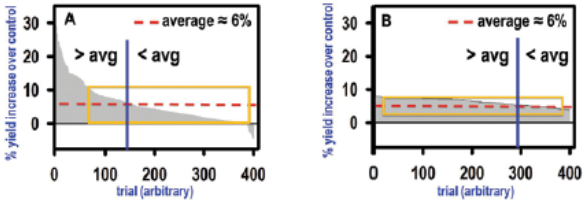
Articles in university and industry publications (local-national readership/circulation)

Researchers share five 'fast facts' to help growers understand biofertilizers

By Matthew D. Kleinhenz

An increasing number of products containing microbes as the primary active ingredient are being marketed to growers looking to enhance: a) crop growth, b) nutrient acquisition, uptake, or utilization, c) tolerance to stress (e.g., temperature, moisture), and/or d) yield. However, the effectiveness of many products is undocumented, leaving growers and advisors to assess efficacy and potential product return on investment.

A team led by The Ohio State University is assisting with that process by conducting on-station and on-farm evaluations and creating resources and educational opportunities helping guide product selection, use, and evaluation. Products are tested under a range of conditions – so far, 21 sites over seven states have been employed in experiments involving seven crops, 13 products, and 10 companies. For details, see u.osu.edu/vegprolab/research-areas/vegebiostimsferts.



These simulated plots represent results from two typical scenarios, A and B (left and right). Both scenarios result in the same average yield increase, but Scenario B may be more favorable to the grower. The position of the upright line shows that yield increases occurred in far more cases in Scenario B than in A, as depicted by the location of the upright line connecting the trial axis to the dashed average line. The yellow rectangle around the average line represents the variation in yield increases; it is thinner in Scenario B, also a plus for product users and their advisors.

Microbe-containing crop biostimulants or biofertilizers are popular among growers and a growing source of revenue for product manufacturers and suppliers. Yet, many questions are unanswered. How should they be used? Are they effective? Do they offer a consistently positive return on investment? While more research is needed to address these questions in detail, the following five "Fast Facts" can help growers make informed decisions about using these products.

Fact One: They are numerous and diverse in important ways. We have tracked the number of these products and companies offering them since March 2015. Currently, we know of 247 OMRI-listed microbe-containing crop biostimulants offered by 105 companies in the U.S.[1]. The number of products and companies in this category have risen 1.6- and 1.5-fold, respectively, in three years. Also, individual products contain either an array of microbes (e.g., multiple types of bacteria, fungi, or both) or a much smaller subset (e.g., single species of bacteria). Some products also contain components designed to feed the microbes, crop, or both.

Fact Two: Overall, labeling and third-party documentation of efficacy are weak. Compared to fertilizers, biopesticides, and other inputs, regulation of microbe-containing crop biostimulants is minimal and inconsistent, with much state-to-state variation. Labels can lack complete or accurate descriptions of package contents or detailed instructions for use. Currently, there is no systematic, third-party, state, regional, or national testing system or mechanism for developing efficacy information (unlike for biopesticides). Companies appear to differ significantly in the amount and rigor of third-party testing they conduct. As one consequence of this "Wild West" scenario, the best evidence of efficacy on farms is often not publicly available since farmer-focused, research-based reports featuring these products are rare.

Fact Three: They are increasingly popular among organic and other growers in the U.S. and globally. Projections are for the U.S. biofertilizer market (including products in which "microbes do

of the conditions under which they are used. With support from USDA, SARE, various companies, and others, we and our collaborators work to develop resources that lessen some of the mystery around selecting, using, and evaluating microbe-containing crop biostimulants.

Fact Five: Ways in which these products work (modes of action) can lead to application effects being more subtle than with other inputs. Inoculated plants may grow a little faster, flower a little sooner, and appear to be healthier (e.g., in color) in a range of conditions but not yield considerably more. Of course, these differences will be apparent only when an untreated check area is available for comparison. Regardless, documented inoculant effects will allow users to know exactly what they can/should expect from a product and to be certain it is what they want to pay for.

In replicated trials, statistically significant yield increases are rare and usually don't exceed 6-7%. It's common to see a range of responses to inoculation with a single product—over different trials in different seasons and involving different crops. Companies and investigators may consolidate responses from many trials into graphs resembling ones in the figure. The shape of the graph for a product is at least as important to growers as the average yield response, which is the most commonly reported statistic. The shape of the graph and, by association, the most frequently occurring yield response, may be a more reliable indicator of what growers should expect from the product. So, when inquiring about a product, consider asking for either the distribution of yield responses across trials and/or the most frequently occurring yield response, in addition to the average.

There is a tangible, justifiable, and widespread enthusiasm for the idea that purposeful inoculation of seeds, crops, and/or soils with beneficial microbes (*e.g.*, bacteria, fungi) may enhance farm success and environmental stewardship. Inoculation would complement steps fostering the development and activity of naturally occurring, beneficial microbial communities. Being enthusiastic about opportunities created by inoculation is easy: so far, it rarely results in *lower* yield, it *may* result in higher yield, and it is often thought of as "cheap enough."

However, the goal is to ensure that inoculation offers more growers a greater return on investment more often. Achieving that goal definitely requires more information and it may require better products.

Based on these five fast facts, researchers offer these recommendations: First, stay tuned to reports from the microbe-containing crop biostimulant industry and trusted sources; second, experiment with biostimulants using reliable guidelines—such as SARE's How to Conduct Research on Your Farm or Ranch[4]—and engage with others involved in this research. The Ohio State University Vegetable Production Systems Laboratory manages a listserv for vegetable producers to share information and field experiences with microbial-based biostimulants. To join, see u.osu.edu/vegprolab/research-areas/vegebiostimsferts.

Matthew Kleinhenz is a professor in Horticulture and Crop Science at The Ohio State University, Wooster, Ohio. Julie Laudick, Stephanie Short, Zheng Wang, and Nicole Wright contributed to the content of this article.

References

1. u.osu.edu/vegprolab/microbe-containing-bioproducts
2. www.grandviewresearch.com/industry-analysis/biofertilizers-industry
3. Laudick, J. et al. 2016. M.S. Thesis. The Ohio State Univ.; Microbial biostimulants in organic farming systems: patterns of current use and an investigation of their efficacy in different soil environments.
4. www.sare.org/Learning-Center/Bulletins/How-to-Conduct-Research-on-Your-Farm-or-Ranch

Articles in university and industry publications (local-national readership/circulation)

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Best Practices to Effectively Utilize Biostimulant Technology

The use of biostimulants in agriculture has been growing rapidly despite considerable uncertainty regarding their mode of action and appropriate use. Many biostimulants are believed to function through their ability to mitigate the negative effects of mild to moderate plant stress and improve crop resilience under resource competition, thereby enabling the full realization of yield potential.

Professor Patrick Brown
Department of Plant Sciences
University of California-Davis, *USA*

To optimize crop response to biostimulants it is therefore critical that users understand the sensitivity of their crop to stress events and have a sound understanding of the purported mode of function of the biostimulant being used. In this seminar we will explore current hypotheses on the mode of action of many biostimulants and the principles that underlie their effective use.

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Literatures

- refereed scientific
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Today's Topics

- impacts? (consistent, statistically significant)
- biostimulant science
- place in toolbox

Biostimulants

Microbial Biostimulants

- Bacteria
- Fungi
- Bacteria and Fungi

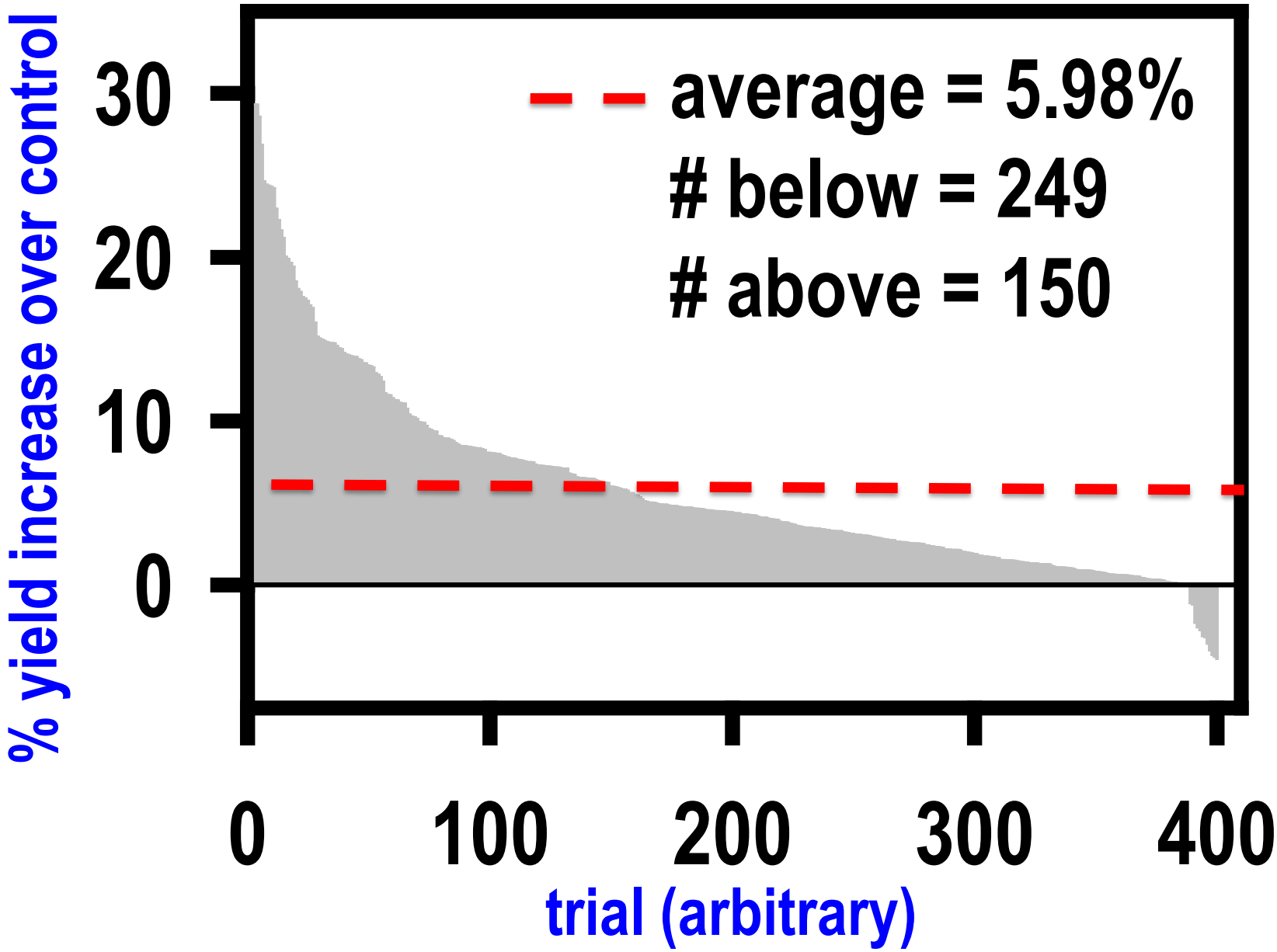
Other Biostimulants

Containing one or more microbes as a leading, if not THE primary active ingredient, sets these products apart.

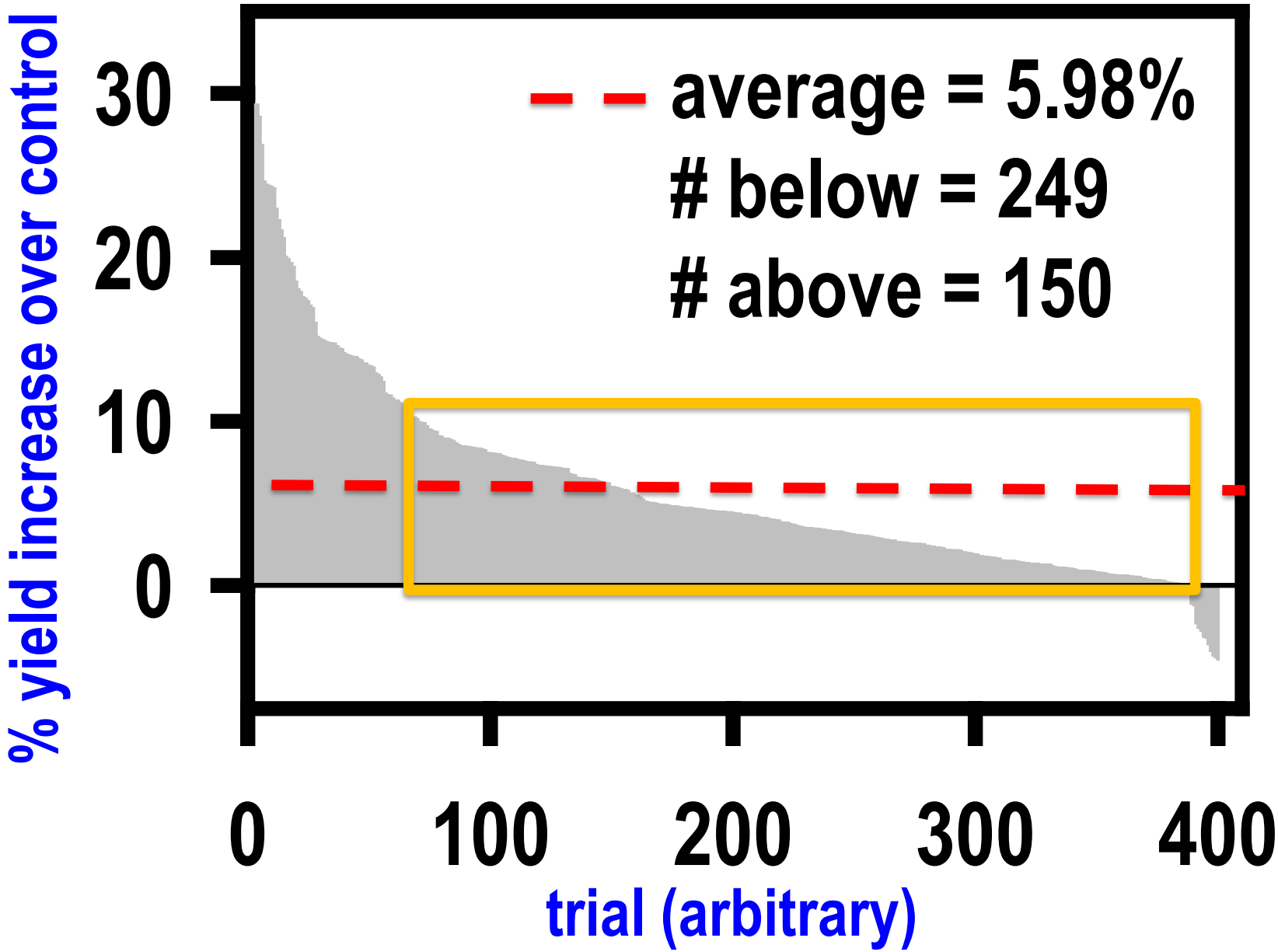
Microbe-containing Biostimulants

- in widespread trialing, effects have been case-specific (i.e., inconsistent) and yield increases, if any, have rarely exceeded 5%

Common Profile of Results of Microbial Biostimulant Yield Trials



Common Profile of Results of Microbial Biostimulant Yield Trials



Yield enhancement, if any, occurs on a case by case basis, probably influenced by soil status and application and other factors.

… **prevailing narrative in the scientific literature is that response to inoculation (e.g., percent growth enhancement) is most often greater in low-fertility environments.**

***Other narratives exist*.**

Scientia Horticulturae 196 (2015) 3–14

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Review

Plant biostimulants: Definition, concept, main categories and regulation

Patrick du Jardin

Plant Biology Unit, Gembloux Agro-Bio Tech, University of Liège, Belgium, 2, Passage des Déportés, B-5030 Gembloux, Belgium

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Biofertiliser
Definition
Regulation

ABSTRACT

A plant biostimulant is any substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits, regardless of its nutrients content. By extension, plant biostimulants also designate commercial products containing mixtures of such substances and/or microorganisms. The definition proposed by this article is supported by arguments related to the scientific knowledge about the nature, modes of action and types of effects of biostimulants on crop and horticultural plants. Furthermore, the proposed definition aims at contributing to the acceptance of biostimulants by future regulations, especially in the EU, drawing the lines between biostimulants and fertilisers, pesticides or biocontrol agents. Many biostimulants improve nutrition and they do so regardless of their nutrients contents. Biofertilisers, which we propose as a subcategory of biostimulants, increase nutrient use efficiency and open new routes of nutrients acquisition by plants. In this sense, microbial biostimulants include mycorrhizal and non-mycorrhizal fungi, bacterial endosymbionts (like *Rhizobium*) and Plant Growth-Promoting Rhizobacteria. Thus, microorganisms applied to plants can have a dual function of biocontrol agent and of biostimulant, and the claimed agricultural effect will be instrumental in their regulatory categorization. The present review gives an overview of the definition and concept of plant biostimulants, as well as the main categories. This paper will also briefly describe the legal and regulatory status of biostimulants, with a focus on the EU and the US, and outlines the drivers, opportunities and challenges of their market development.

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   2.2. Protein hydrolysates and other N-containing compounds 5
   2.3. Seaweed extracts and botanicals 5
   2.4. Chitosan and other biopolymers 6
   2.5. Inorganic compounds 6
   2.6. Beneficial fungi 6
   2.7. Beneficial bacteria 7
3. Common features of biostimulants 7
4. Defining plant biostimulants : aiming at a consensus 8
5. Regulation of plant biostimulants 9
6. Developing the market : opportunities and challenges 10
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Microbial Biostimulants in Organic Farming Systems: Patterns of Current Use and an Investigation of Their Efficacy in Different Soil Environments

THESIS

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in the Graduate School of The Ohio State University

By

Julie Laudick

The Environmental Science Graduate Program

The Ohio State University

2017

Master's Examination Committee:

Dr. Matthew Kleinhenz, Advisor

Dr. Enrico Bonello

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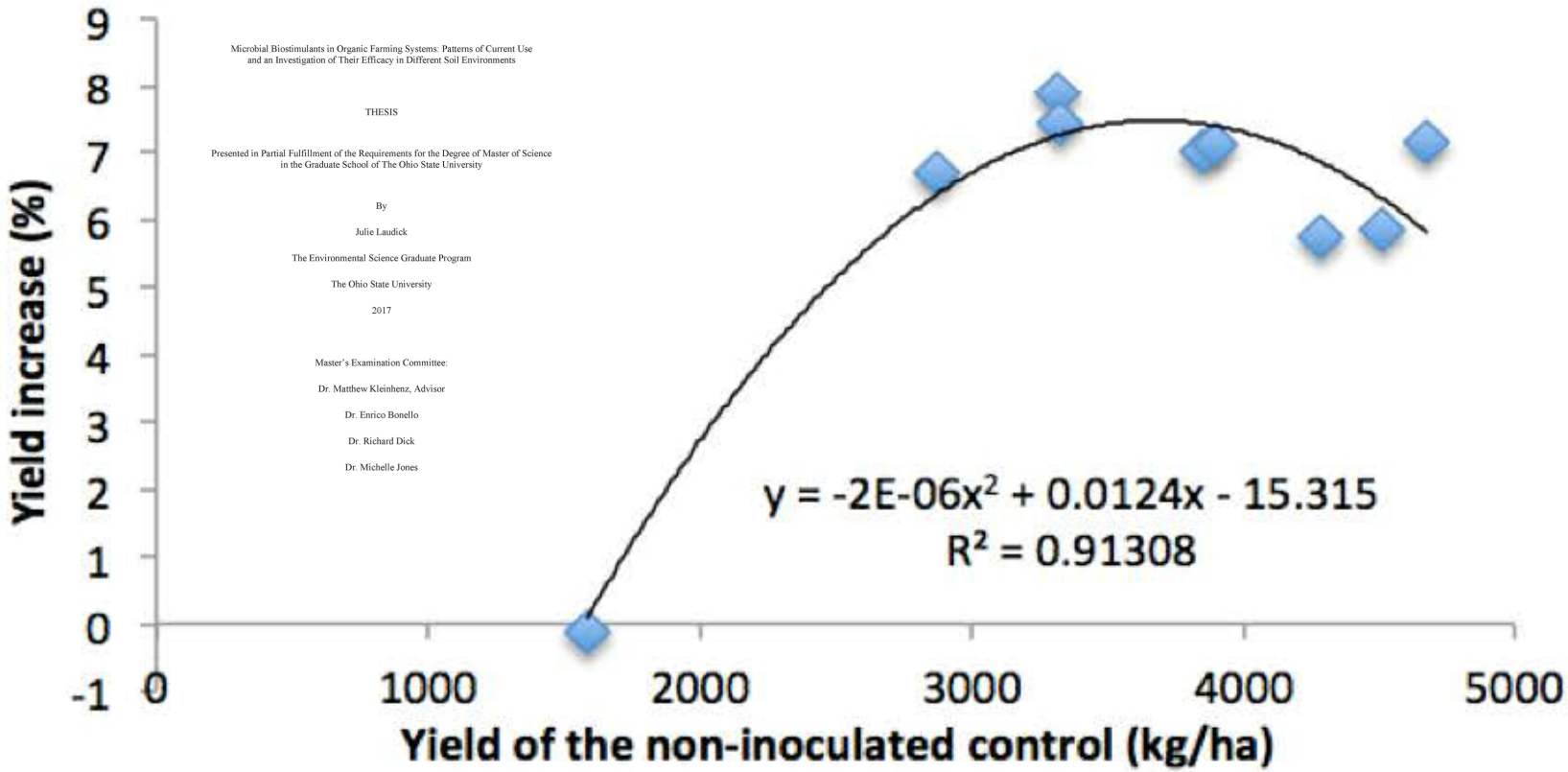

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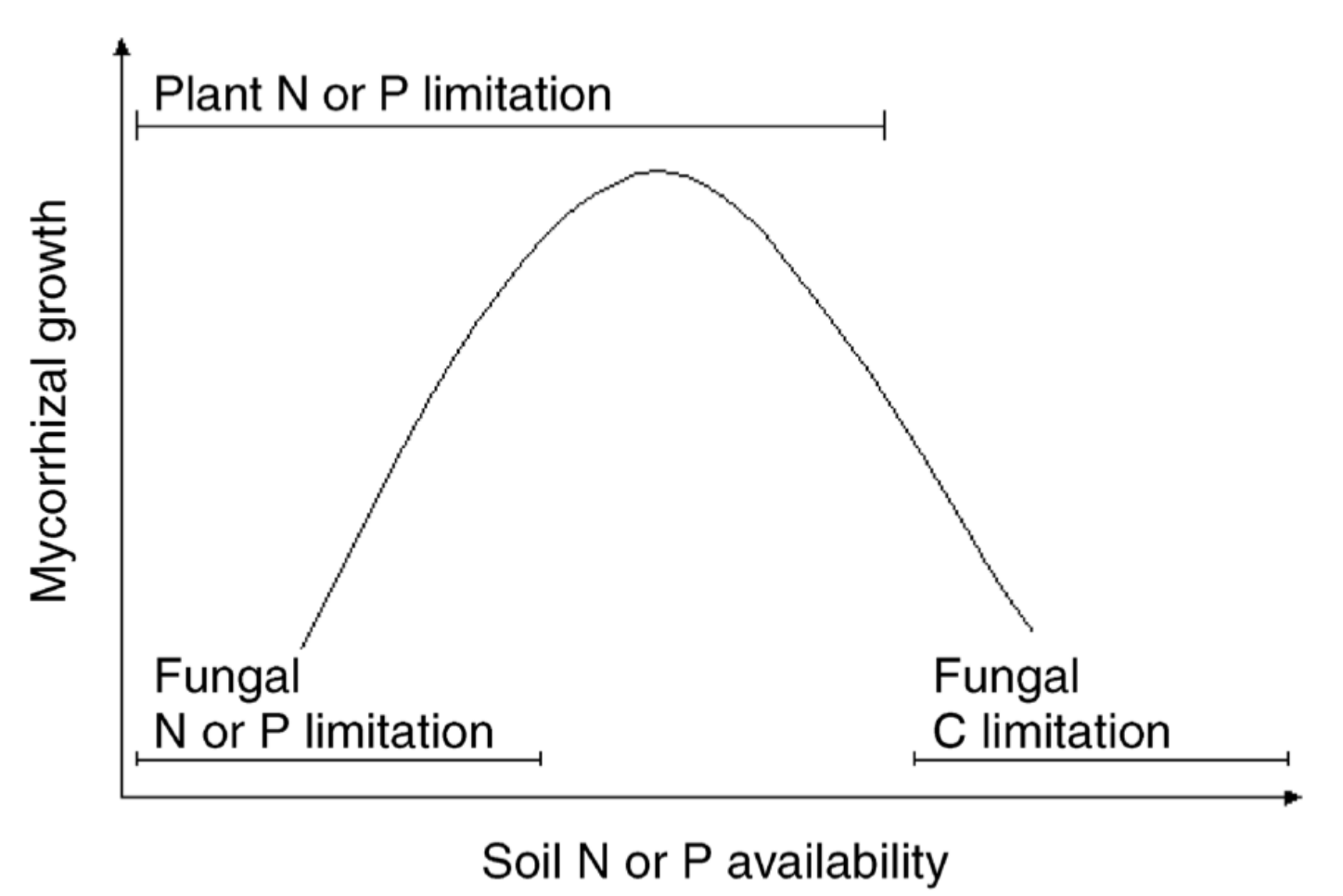
Figure 3.3 Percent yield increase of wheat due to inoculation with *Azospirillum* brasilense was based on mean values reported for 10 soil types, and charted against the yield of the non-inoculated control for each soil type. Yield response to inoculation appears to have a quadratic relationship with the control yield for a given soil type. This graph was generated using data from a study of dryland wheat at 297 field sites including 10 soil types (Díaz-Zorita and Fernández-Canigia 2009)

Example: growth of mycorrhizal fungi greatest in soils intermediate in nutrient availability



Treseder, K.K., and Allen, M.F. (2002). Direct nitrogen and phosphorus limitation of arbuscular mycorrhizal fungi: a model and field test. New Phytol. *155*, 507–515.

soil status ⟷ bio-stimulant

soil health-biostimulant relationships are neither settled science nor practice.

Today's Topics

- impacts?
  (consistent, statistically significant)
- **biostimulant science**
- place in toolbox

Microbe-containing Biostimulants

- continue a two-century old expectation that increasing the numbers of beneficial microbes in the crop root zone, including with inoculants, is worthwhile.

  - PGPR commercialization began in 1895 in U.S. and UK with inoculating legumes with rhizobia.

The Problem

enthusiasm over the potential benefits of inoculation or treatment with MCCBs

research-based resources to guide the process in ways resulting in worthwhile ROIs

(Microbe-containing) Biostimulants

- currently, minimally and inconsistently regulated in the U.S.;
  ‘weak’ testing system

“Wild West” of input categories and industries

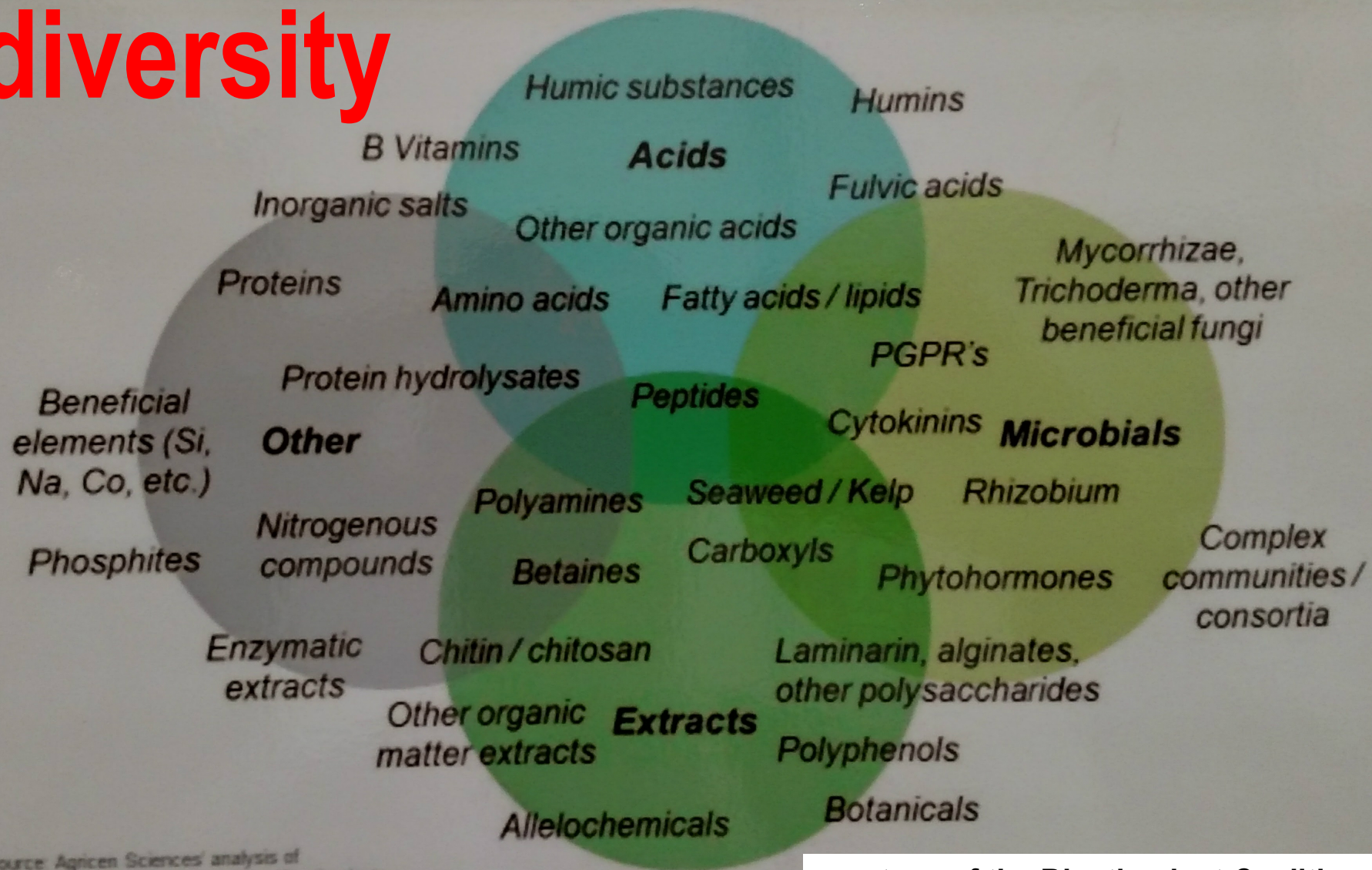
(Microbe-containing) Biostimulants

- no clear mechanism to develop research-based, third-party, user-friendly info analogous to that for (bio-)pesticides (e.g., IR-4) and other (more regulated) inputs

Facts Slowing the Progress of Certain Types of User-Focused Research involving (Microbe-containing) Biostimulants

The Emerging Landscape of Products – Broad and (Potentially) Confusing

diversity



Source: Agricen Sciences' analysis of market analysts, survey papers on Biostimulants

courtesy of the Biostimulant Coalition

Important Dates		Number of OMRI-listed Products
OMRI List	Our Updated List	
March 3, 2015	March 3, 2015	150
July 9, 2015	July 14, 2015	161
January 7, 2016	January 19, 2016	166
May 18, 2016	May 19, 2016	174
August 22, 2016	August 23, 2016	174
November 7, 2016	November 8, 2016	177
February 13, 2017	February 13, 2017	173
July 31, 2017	August 7, 2017	207
November 7, 2017	November 22, 2017	235
March 15, 2018	March 29, 2018	247
October 23, 2018	November 15, 2018	344

2.3- and 2.2-fold increases in # of products and companies, resp., in last 3 years

Abundance

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Information in the database was obtained from OMRI, manufacturer documents and Material Safety Data Sheets (MSDS).

Information is incomplete for some products; information will be added as it becomes available and as resources allow.

The interface is interactive and is designed to become more so in time. Currently, fields of information can be sorted and searched and links can be selected to obtain additional information. Links to technical reports on and user-re its entirety by clicking on the "view" link located directly to the f the product name. Columns can be hidden from view by clicking on the menu arrow that appears to the right of the column name. To unhide a column, hit the F5 key o

Microbe-containing products differ in the microbes and other ingredients they contain and in methods used to apply them. For various reasons, two products containing the same or similar organism(s) may perform differently in the

Please click here to provide feedback on and suggestions for improving the interface.

Please click here if you have trouble accessing or using the interface.

This interface was developed with the support of The OSU Department of Horticulture and Crop Science and the Center for Applied Plant Sciences.

To view in original mode, click here. To return the Vegetable Production Systems Laboratory website, click here.

OMRI-listed on August 22, 2016	Product	Target Crops	Third Party Trials	Industry-based Trials	Key Ingredients	Other Ingredients	Modes of Application	Storage/Shelf Life	Developer/Manufacturer	Address
Yes	MycoApply Super Concentrate - Super Concentrate 1	TBD			Glomus aggregatum, Glomus etunicatum, Glomus intraradices, Glomus mosseae		TBD	TBD	Mycorrhizal Applications, Inc.	P.O. Box 1029
Yes	MycoApply Super Concentrate - Super Concentrate 10	TBD			Glomus aggregatum, Glomus etunicatum, Glomus intraradices, Glomus mosseae		TBD	TBD	Mycorrhizal Applications, Inc.	P.O. Box 1029
Yes	MycoApply Super Concentrate - Super Concentrate 100	TBD			Glomus aggregatum, Glomus etunicatum, Glomus intraradices, Glomus mosseae		TBD	TBD	Mycorrhizal Applications, Inc.	P.O. Box 1029
Yes	Activate 1005	TBD			Bacillus subtilis		TBD	TBD	Natural Resources Group	34284 B Rd. 196

- **http://u.osu.edu/vegprolab/microbe-containing-products/**
- **344 OMRI-listed MCBSs; first searchable and sortable online portal focused on delivering information for growers, grower advisors, members of industry, researchers**
- **2316 pageviews representing 33 countries and 48 US states (2015-2018)**

Number of distinct species (bacteria and fungi) contained in OMRI-listed biostimulants.

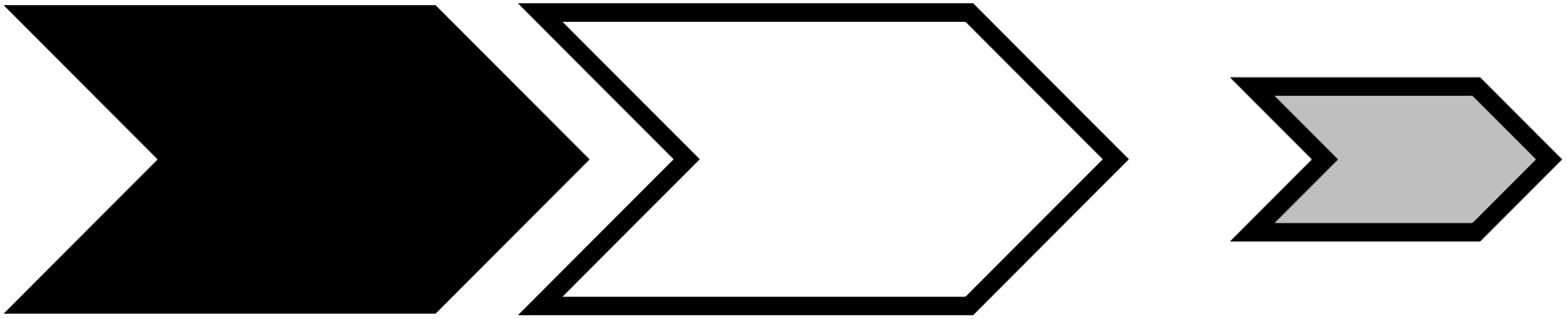
Bacteria		Fungi	
Rhizobia	Other bacteria	Mycorrhizal fungi	Other fungi
14	61	31	19

Number of products with the microbial compositions listed.

	bacteria only	fungi only	bacteria and fungi
One genus	25	44	N/A
One genus, >1 species	8	22	N/A
Multiple genera	28	10	34
Total	55	73	34

A MAJOR REASON

Stages in Product Pipeline and Adoption and Relative Effort given to Each



1. Discover or identify, characterize
2. Formulate, package, deliver
3. Select and use on working farms with demonstrated efficacy (ROI)

Strength of evidence regarding effectiveness on farms

-

+

- ***Rhizobia***
  legumes … yes
- **Mycorrhizal Fungi**
  Brassica … no

host-/crop-specificity

Strength of evidence regarding effectiveness on farms

\- +

- *Azotobacter*
- *Azospirillum*
- *Bacillus*
- *Pseudomonas*
- Mycorrhizal Fungi

on most crops … yes

Strength of evidence regarding effectiveness on farms

-

+

- dozens of other microbe-crop combinations

- multiple modes of action, some incompletely characterized, leading to subtle, ‘finicky’ application effects

… difficult to quantify and assign value and to publish, if needed

Table 1
Effects of biostimulants on crop productions, from their cellular targets in plants to whole-plant physiological functions, to agricultural/horticultural functions, and ultimately to expected economic and environmental benefits (Dobbelaere et al., 1999; Huang et al., 2010; Shabala et al., 2012).

	Humic acids	Seaweed extracts	Protein hydrolysate	Glycine betaine	Plant Growth-promoting Rhizobacteria
Cellular mechanism (*i.e.* interaction with cellular components and processes) ↓	Activate plasma membrane proton-pumping ATPases, promote cell wall loosening and cell elongation in maize roots (*Zea mays*) (Jindo et al., 2012)	*Ascophyllum nodosum* extracts stimulate expression of genes encoding transporters of micronutrients (*e.g.* Cu, Fe, Zn) in oilseed rape (*Brassica napus*) (Billard et al., 2014)	Enzymatic hydrolysate from alfalfa (*Medicaco sativa*) stimulates phenylalanine ammonia-lyase (PAL) enzyme and gene expression, and production of flavonoids under salt stress (Ertani et al., 2013)	Protects photosystem II against salt-induced photodamage in quinoa (Shabala et al., 2012), likely via activation of scavengers of reactive oxygen (Chen & Murata , 2011)	*Azospirillum brasilense* releases auxins and activates auxin-signalling pathways involved in root morphogenesis in winter wheat (*Triticum aestivum*) (Dobbelaere et al., 1999)
Physiological function (*i.e.* action on whole-plant processes) ↓	Increased linear growth of roots, root biomass	Increased tissue concentrations and root to shoot transport of micronutrients	Protection by flavonoids against UV and oxidative damage (Huang et al., 2010)	Maintenance of leaf photosynthetic activity under salt stress	Increased lateral root density and surface of root hairs
Agricultural/horticultural function (*i.e.* output traits relevant for crop performance) ↓	Increased root foraging capacity, enhanced nutrient use efficiency	Improved mineral composition of plant tissues	Increased crop tolerance to abiotic (*e.g.* salt) stress	Increased crop tolerance to abiotic (*e.g.* high salinity) stress	Increased root foraging capacity, enhanced nutrient use efficiency
Economic and environmental benefits (*i.e.* changes in yield, products quality, ecosystem services)	Higher crop yield, savings of fertilisers and reduced losses to the environment	Enhanced nutritional value, 'biofortification' of plant tissues (increased contents in S, Fe, Zn, Mg, Cu)	Higher crop yield under stress conditions (*e.g.* high salinity)	Higher crop yield under stress conditions (*e.g.* high salinity)	Higher crop yield, savings of fertilisers and reduced losses to the environment

Microbe-containing Biostimulants

Work in 5 Main Ways (can be related)

1. Increase nutrient availability
2. Plant hormones (produce, trigger)
3. Limit plant stress
4. Extend root systems
5. Suppress pathogens, induce resistance

Success (i.e., growth promotion) in research (especially in ‘artificial’ settings).

≠

Success (i.e., greater profit) on farms.

- unclear product-product interactions

… reductionistic,
input substitution or
holistic model?

- category’s credibility problem hampers the recruitment of committed investigators, especially early-career, and sufficient funding

Selected U.S.-based Microbial Biostimulant Investigators

- Ute Albrecht, *University of Florida*
- Patrick Brown, *University of California-Davis*
- Tim Coolong, *University of Georgia*
- Lori Hoagland, *Purdue University*
- Sam Wortman, *University of Nebraska-Lincoln*

- David Holden, *Holden Research and Consulting*
- John Kempf, *Advancing EcoAgriculture*

Biostimulants

Three Factors Influencing Research Topics and Directions

USDA United States Dep

Agricultural Marketing Service

SPECIALTY CROPS

http://www.wisfarmer.com/news/root-system-of-corn-plant----especially-important-in-drought-----jcpg-294488-171547901.html

main interest in the soil-microbe-crop continuum

basic/
fundamental

applied

microbial
ecology

targeted use of
microbes in
production

interests, roles/responsibilities define activities

Applied Biostimulants Research Questions

- best application procedures, including 4 R's?
- host-specificity, if applicable?
- soil and cropping conditions?
- interactions with other inputs, (e.g., pesticides) and practices?
- appropriate evaluation metrics?
- thresholds for acceptance (ROI)?

Direction reflects funding, support. Overall, applied biostimulant research relatively difficult to fund.

PROJECT SUMMARY

Title: Examining and Utilizing the Microbiome in Controlled Environment Agricultural Systems to Improve Productivity, Food Safety and Sustainability

PD: Christopher G. Taylor **Institution:** The Ohio State University

CO-PD/PI's: Bhavik Bakshi, Maria Soledad Benitez Ponce, Alison Bennett, Joshua Blakeslee, Shauna Brummet, Luis Canas, Jessica Cooperstone, David, Francis, Rachel Gabor, Sanja Ilic, Melanie Lewis Ivey, Michelle Jones, Matthew Kleinhenz, Chieri Kubota, Subbu Kumarappan, Jiyoung Lee, Peter Ling, Tea Meulia, Frederick Michel, Sally Miller, Uttara Samarakoon Basnagala, Matthew Smith, Ye Xia

The widely recognized, unmatched potential of Controlled Environment Agriculture (CEA) to address growing food security-related concerns will be achieved only when lingering challenges in CEA are adequately addressed. Although more reliable, productive, and efficient than open field systems, the potential of CEA is limited by high costs and the need for ever-greater efficiency and improved sustainability, knowledge gaps in understanding the impacts of its associated microbiome on crop, human, and business metrics, and the shortage of qualified labor. We will address all four issues directly using a transdisciplinary approach integrating our research, extension, and education capacities along with our long-standing relationships with CEA stakeholders. Decades of experience in engineering, plant physiology, biochemistry, and genetics, microbiology, food science and safety, modeling, economics, and other areas will be directed to cutting-edge science grounded in current and emerging private-sector challenges. Studies completed in working and experimental CEA systems and engaging investigators and stakeholders differing in age, experience, discipline, affiliation, and perspective will help insure that research is highly credible and useful, no matter the audience. Moving forward in our understanding of how various inputs shape growth, yield, nutrition, and water quality is a goal, along with documenting the composition and function of CEA microbiomes as a necessary first step in learning how to alter them for peoples' benefit. The collecting and distributing of science-based knowledge, improving CEA system literacy in stakeholders, and preparing the next generation CEA workforce along with a strategy to fund new ideas are hallmarks of this project.

a. Title of Project: Strengthening the sustainability of the U.S. greenhouse industry through effective use of biological products.

(This is a resubmission of NIFA proposal #2018-03403, which was ranked High Priority)

b. Type of project to be submitted: Coordinated Agricultural Projects (CAPs)

c. Anticipated amount of funding to be requested: $6,200,000 (4 years)

d. Economic/environmental/social significance of the problem being addressed and
e. Potential economic/environment/social benefit to solving the problem being addressed:

The continued success and future growth of the U.S. greenhouse industry is dependent on improving the sustainability of greenhouse production systems. The current retail value of the greenhouse industry in the U.S. is well over $12 billion. While the demand for ornamental plants continues to rise steadily, edibles such as herbs and vegetables, represent the largest growth area for the industry, bringing great opportunity and challenges (Greenhouse Grower Magazine 2017 State of the Industry Whitepaper). The widening gap between production costs and revenues is emerging as a significant barrier to the profitability of the U.S. greenhouse industry. Similarly, traditional production systems, which rely on the use of synthetic pesticides and fertilizers, do not align with worker and customer expectations regarding sustainability.

Commercial greenhouse production systems have traditionally relied heavily on the use of chemical pesticides and intense fertilization to control pathogens and insects and to ensure the timely production of quality crops. Traditional crop production and protection protocols can place growers, workers, and the environment at risk. While effective, costly synthetic fertilizers and pesticides undermine worker and environmental safety agendas. They also drive wedges between edible and ornamental crop suppliers and the growing community of buyers applying different standards when exerting their purchasing power. For an increasing number of customers and retailers, healthy, attractive products are insufficient; they must arrive in that condition having been grown using sustainable worker- and environmentally-responsible approaches. Conserving and protecting resources, including water, while meeting traditional crop quality standards is essential. Adjusting management programs to make better use of biological products (biopesticides and biostimulants) is an attractive solution to both the profitability and worker and customer expectations issues. However, despite much promise, management programs built around the use of bioproducts have been unreliable thus far. Our work over the last three years has revealed reasons for this and possible solutions.

First, we (the Bio4 Greenhouse Team) were awarded a NIFA SCRI planning grant to assess the U.S. greenhouse industry's interest in and knowledge of different classes of biological products, including biopesticides and biostimulants. Among other findings, our industry survey confirmed that most greenhouse growers were interested in using biological products as part of a more sustainable crop production system. Next, our follow-up 2016 strategic planning workshop -- attended by a significant cross-section of the industry and its associated university research and extension community -- identified five obstacles that have limited the use of biological products in commercial greenhouses. These included slower action, higher costs, lack of experience with biological products, inability to use them with current management practices, and a lack of efficacy data. Our research and dialogue with the industry and the project's Stakeholder Advisory Committee are ongoing. Through them, we have come to recognize that

Summary

Microbe-containing Biostimulants

- growers, investigators, and grower advisors have a mix of positive and negative views on these products

Microbe-containing Biostimulants

Thought process leading growers to at least experiment with if not use them regularly.

1. Some microbes are good, others are bad, and others people aren't sure about.
2. Companies have identified potentially helpful microbes and packaged them in ways allowing inoculation ("pill", yogurt, probiotic).
3. Products are very unlikely to cause harm and they just may help. And, most of the time, per-acre costs are not prohibitive.
4. So, inoculation is worth it.

Today's Topics

- impacts?
  (consistent, statistically significant)
- biostimulant science
- **place in toolbox**

Microbial-based Crop Biostimulants: Their Place in the Toolbox

- still being discovered
- defined farm-farm, crop-crop; use multiple approaches

Microbe-containing Biostimulants

- obvious potential and popularity; great assets
- strengthening their position in growers' toolboxes will require patience and information

Microbe-containing Biostimulants

- fast-moving, still-evolving industry and category of inputs … wise to pay attention

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THANK-YOU and GOOD LUCK!

QUESTIONS?

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The OSU-OARDC

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