34th Annual
NATIONAL NO-TILLAGE CONFERENCE®
January 6-9, 2026 ▪ St. Louis, Mo.

What's Happening in Biologicals for Pest Management & Plant Health

Pam Marrone, PhD

All Three Categories of Biologicals are Rapidly Growing

$9.0B (+12% CAGR)

Biopesticides
Biocontrol
Bioprotection

Regulated by the EPA & States

$5.0B (+12% CAGR)

Biostimulants
Crop Enhancement
Stress Reduction

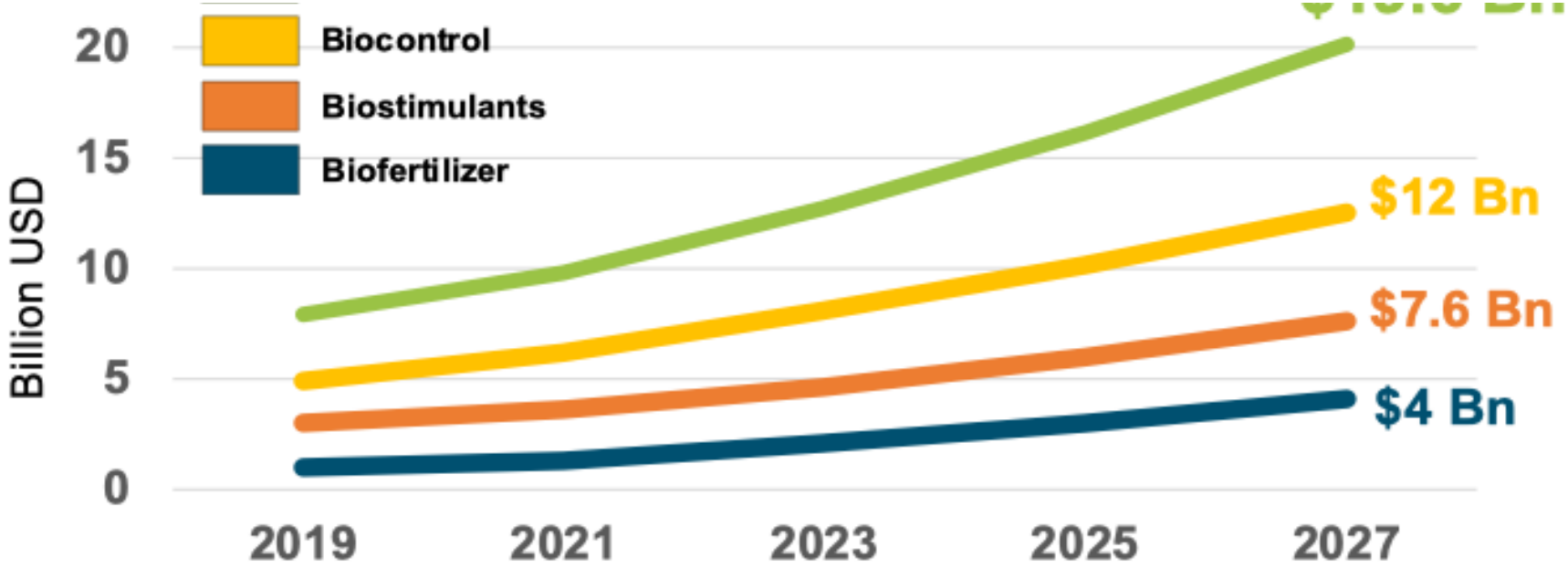
$2.5B (+11% CAGR)

Biofertilizers
Bionutrients

Regulated state by state; National biostimulant standards pending

- Microorganisms, some plant extracts, pheromones, other natural materials and substances
- **Sulfur, copper, pyrethrum, spinosad are NOT biopesticides**

Continued Growth of Biologicals



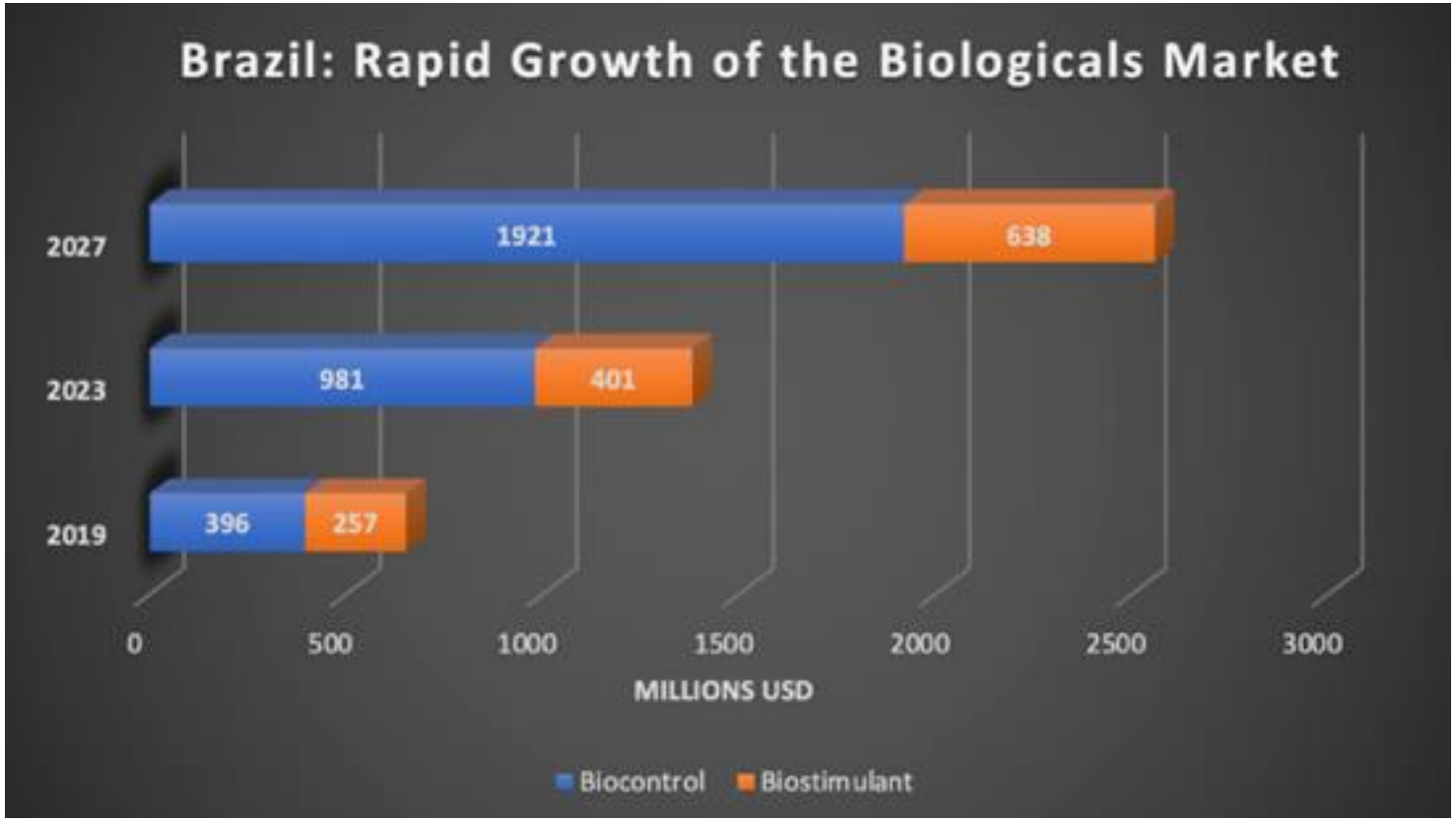
SCIENCE

Enables value **creation**

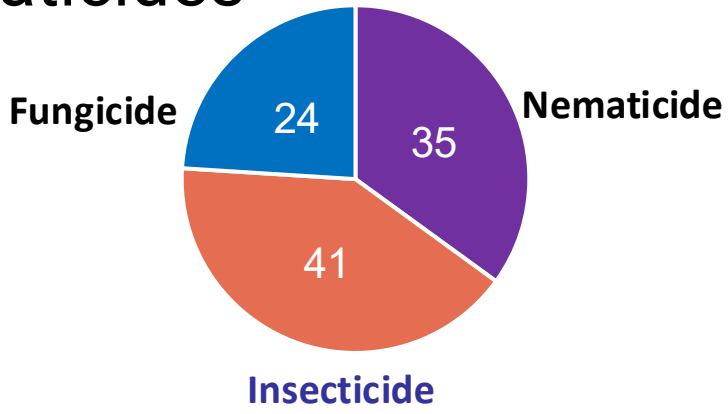
Enables value **capture**

Biocontrol market: 2010 - Now

Brazil Continues its Biologicals Juggernaut
Led by Row Crops



- 13 months for a new biopesticide registration
- Registered ~500 biopesticides in 9 years!
- Bionematicides outsell synthetic chemical nematicides



New and Old Drivers Continue to Spark Growth

Grower ROI

The data continue to support their value

CO_2

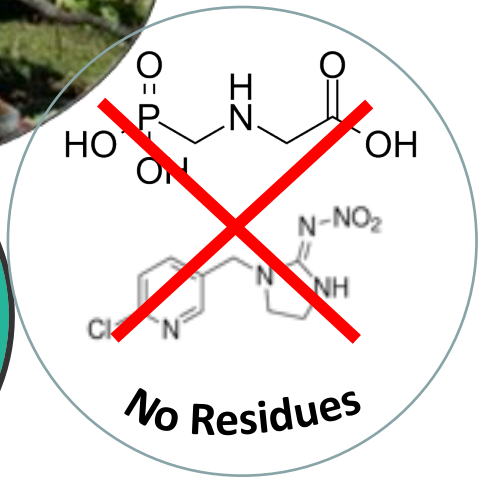
AI Omics ML

New Science Tools Drive Efficacy & Scale

The Fundamentals

<$5 million

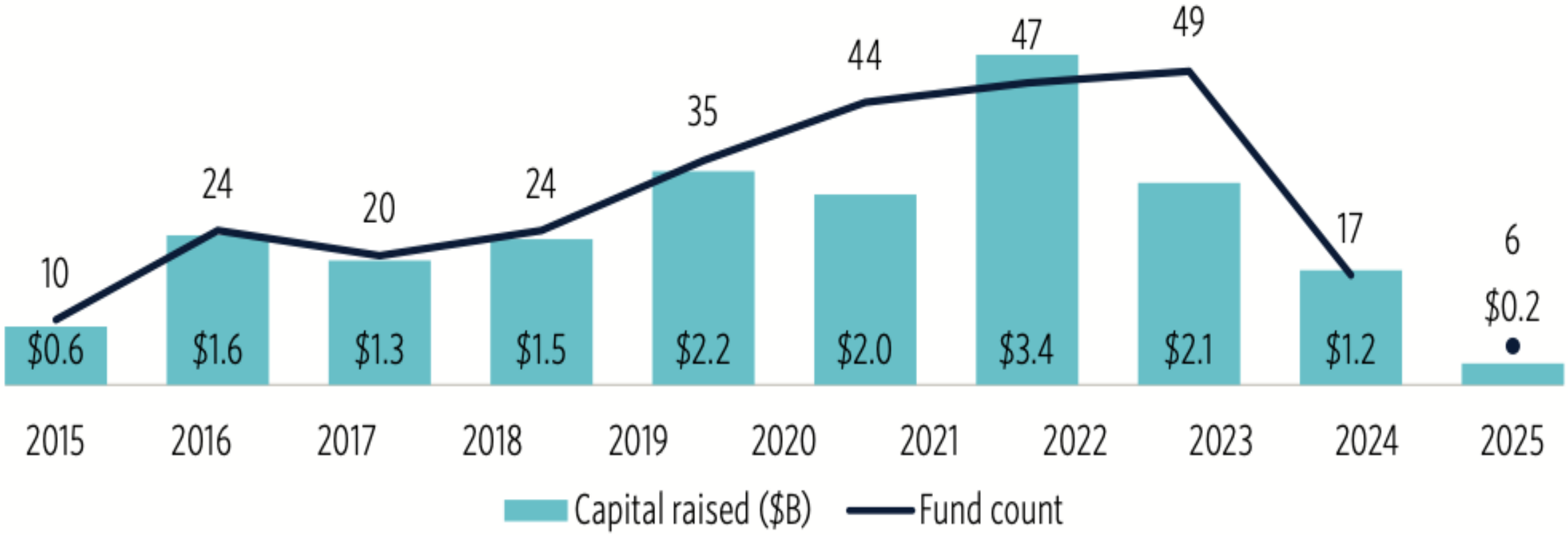
<4 years to develop



More than 70% of Biologicals are Used by Conventional Growers But They are Often Seen as "Just for Organic"

Agrifood VC fundraising activity

Billions of Investment has Driven Growth



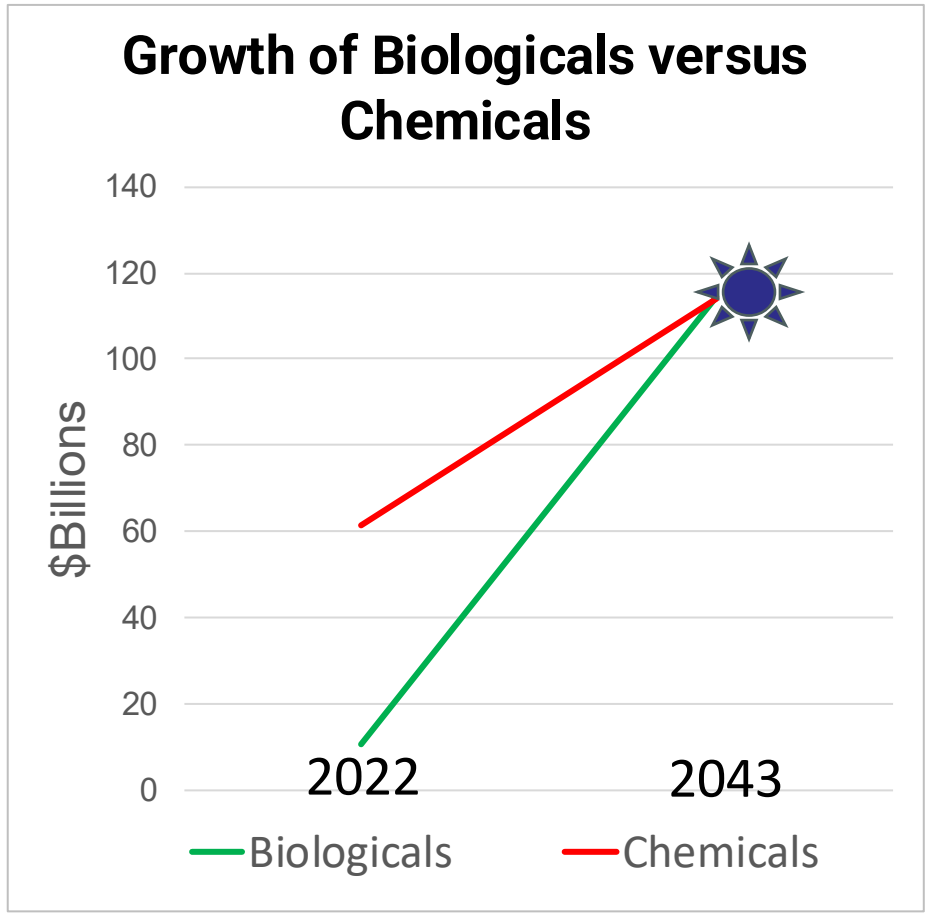
Source: PitchBook • Geography: Global • As of June 30, 2025

Many Deals Among Small and Large Companies

COMPANY	TYPE	AGRIBUSINESS PARTNERS/INVESTORS
micropep	Peptides	FMC, CORTEVA agriscience
VESTARON	Peptides	syngenta, ADM
biotalys	Peptides	syngenta, novonesis, bioBest
SOLASTA	Peptides	FMC, CORTEVA agriscience
puna.bio	Extremophiles for nutrient uptake	CORTEVA agriscience
elemental enzymes	Enzymes, Peptides	CORTEVA agriscience
PLANT HEALTH CARE	Peptides	Nutrien, Agrii, AGER, AMVAC
Elicit Plant	Phytosterols for water stress	Bayer CropScience, BASF, Certis Belchim
INTRINSYX BIO	Endophytes as biostimulants	syngenta
AgroSpheres	Multiple	Bayer CropScience, FMC, WILBUR-ELLIS, BASF, OCP
IBIAG	Nanobodies	Nufarm, Bayer CropScience, CORTEVA agriscience

Adapted from Upstream

Biologicals Market Equal Chemicals in ~20 Years!



Growth rate (CAGR)		12 %
Number of periods	Biologicals	21
Initial value		10,600,000,000 $
Final value		114,520,791,603.36 $

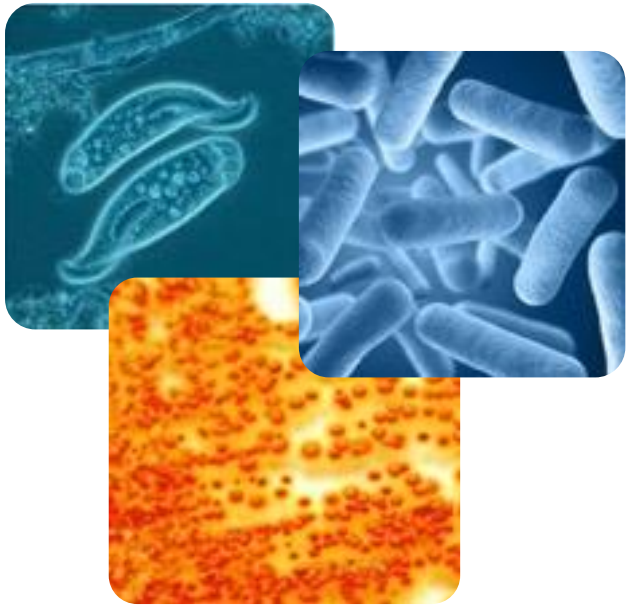
Growth rate (CAGR)		3 %
Number of periods	Synthetics	21
Initial value		61,300,000,000 $
Final value		114,036,057,245.79 $

Adapted from Shane Thomas, Upstream Insights

Upstream

70-80 New Biological Active Ingredients at the Biopesticide Pollution Prevention Division (BPPD) of the EPA

Microbials

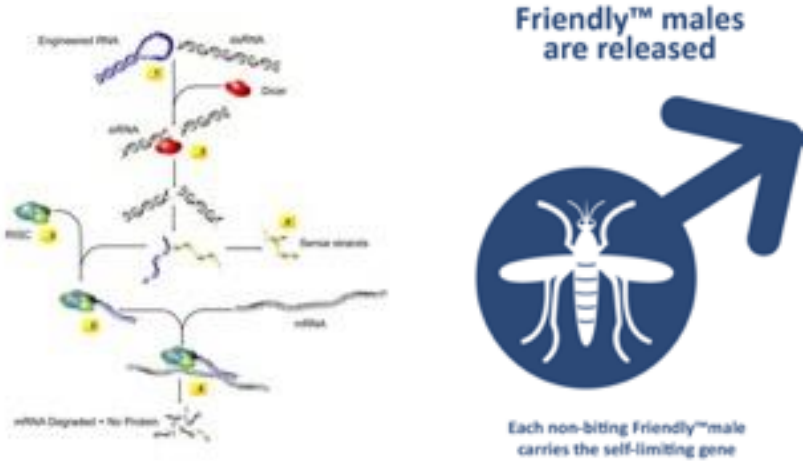


Fungi, Bacteria, Viruses, and Protozoa

Biochemicals

Plant Extracts (some), Pheromones, Soaps, and Fatty Acids

Emerging Technologies



Engineered plants, microorganisms, peptides and insects; RNAi

A 70-year history of safe use of biopesticides

US EPA Biopesticide Registration

Biopesticide Pollution Prevention Division (BPPD)

Tiered Data requirements; Start with Tier I:

- Rat Acute Studies - Oral, Inhalation, Intravenous, Dermal; Rabbit Eye; Guinea pig skin sensitization
- Product chemistry, 5-batch analysis
- Microbiology/QC: no human pathogens
- Ecological effects (non-target birds, fish, *Daphnia*, honeybees, lacewings, ladybeetles, parasitic wasps)
- Endangered species review
- Exemption from tolerance petition (for food use)

California Dept. of Pesticide Regulation requires efficacy data

Chemicals & Biologicals: Different Business Models

Average Chemical Pesticide

Discovery — ***~12 Years & ~$300 Million Development Time & Cost*** — **Launch**

- Massive upfront capital
- Thousands of global field trials on many crops and pests
- Global launch with large marketing spend; Peak sales in 3 years

Biopesticide

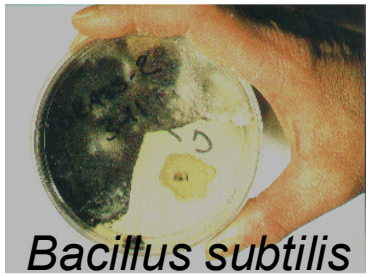
Discovery — **Launch**

3-5 Years & <$10 Million

- Lower cost to develop but peak sales take longer
- EPA registration granted with small number of pests & crops on label
- Commercial development of new versions continues while selling

Examples of Biopesticide Improvements Through Time

AGRA QUEST



Bacillus subtilis
QST #713

Version 1.0

Version 2.0

Version 5.0

Marrone Bio Innovations

Microbe #396
Burkholderia rinojensis sp. nov.

Version 2.0

NEOVO™
INSECTICIDE/NEMATICIDE
POWERED BY RINOTEC™ TECHNOLOGY

ProFarm

ARINO™
INSECTICIDE/NEMATICIDE
POWERED BY RINOTEC™ TECHNOLOGY

BRONTE™
INSECTICIDE/NEMATICIDE
POWERED BY RINOTEC™ TECHNOLOGY

Version 3.0

We Have Only Tapped a Small Portion of Microbial Diversity

***Novel microbes from nature*:**

- **Fix Nitrogen**
- **Sequester carbon**
- **Nutrient use efficiency**
- **Crop residue breakdown**
- **Control difficult pests and pathogens**

LALGUARD JAVA WP *Cordyceps javanica* fungus to control whitefly

Fermentation-enhanced microbial metabolites

Amping up the pesticidal activity

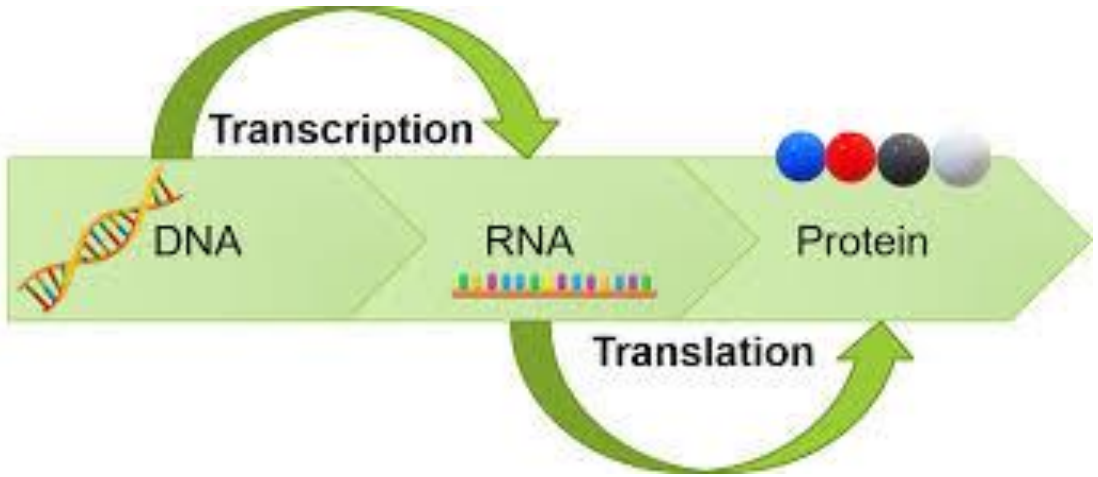
- **Reducing the use rate**
- **Compete with chemicals**

Amoeba extracts as fungicides

RNAi is Quickly Moving Ahead for Crop Protection

RNA is present in all known life forms and plays an essential role in numerous biological processes.

RNAi is short for “RNA interference” and it refers to **a phenomenon where small pieces of RNA can shut down protein translation by binding to the messenger RNAs that code for those proteins**. RNA interference is a natural process with a role in the regulation of protein synthesis and in immunity.



Steady Progress on RNAi Production, Formulation & Delivery

trillium Ag
INNOVATIVE BIO-AGRICULTURE

Agrisomes for delivering RNAi for caterpillars, beetles & bugs

RNAiSSANCE AG

Sprayble RNA pesticides for insect control

GreenLight Biosciences™

- EPA approval CPB, Varroa
- Brazil entry
- Palmer amaranth control
- Submitted for powdery mildew

INNATRIX

Soybean cyst nematode control

robigo

Platform for engineered microbes to deliver dsRNA (soybean biofungicide)

NANOSUR
Ag Biotech

Modified RNAs for crop pests, diseases, weeds

VARADA
AGRICULTURE

RNAi for powdery mildew & Botrytis

RNAway
Breaking Plant Barriers

Our delivery platform enables an effective and practical way to insert RNA into plant cells

PEBBLE LABS

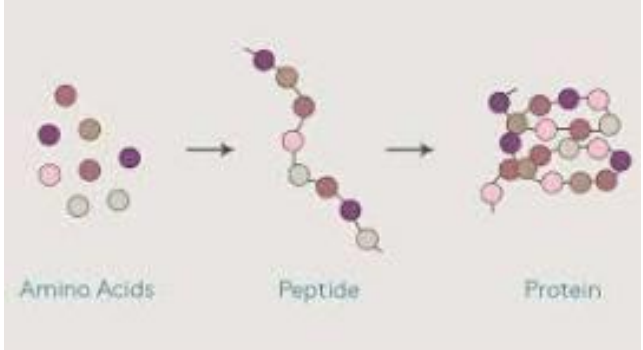
Naturally occurring microbes from crops to deliver the power of RNA (1st product is for *Botrytis*)

AgroSpheres

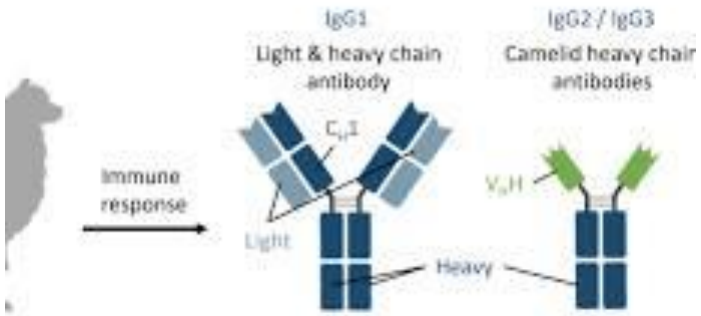
Delivery via Agricell encapsulation technology

Peptide and Nanobodies Innovations are Exploding

Peptides are short chains of amino acids, the fundamental building blocks of proteins. Amino acids are like Lego® bricks; peptides are small Lego structures, while proteins are much larger, complex ones.



Nanobodies are small antibodies that can bind to specific fungal proteins or lipids, disrupting vital functions.



Proteins, Peptides, Antibodies Companies

VESTARON
THE POWER OF PEPTIDES

Spider venom peptides for insect, nematode control

SOLASTA Bio
Nature Inspired

Insect neuropeptides that disturb pest physiological processes

IBIAG

Single Domain Antibody BioControl as Insecticides

genvor

Antimicrobial peptide (AMP) technology

invaio sciences
A FLAGSHIP PIONEERING COMPANY

Peptide innovations to address Citrus Greening

PLANT HEALTH CARE

Harpinαß and PREtec Elicitors, Fungicides & Nematicides

elemental enzymes®

Harnessing naturally occurring enzymes, peptides & biochemistries

biotalys
reinventing food protection

AGROBODY Foundry™ for rapid generation of solutions for a wide range of crop pests and diseases

INNATRIX

Antifungal peptide platform; first is for late blight

micropep

Platform to find Micropeptides of about 10-30 amino acids

QUERCUS
BIOSOLUTIONS

Bringing the power of genAI to create effective and affordable biology-based solutions for crop protection

EPICS Biotechnology

Delivery of proteins & peptides in seeds

Natural Compounds/Plant Extracts for IPM, Plant Health & Yield

LESAFFRE Romeo

Cerevisane, a purified extract of the yeast, *Saccharomyces cerevisiae* Strain LAS117 biofungicide

fyteko The Science of Biopossible

'Signal' molecule capable of 'priming' crops to cope with abiotic stresses as seed treatment

elemental enzymes®

Target essential soil and plant health through enzyme, peptide and biochemistry solutions

Elicit Plant

Phytosterol compounds for water stress tolerance

Sound™ Agriculture

Nature-identical signaling molecules to attract beneficial microbes to the root for N & P uptake

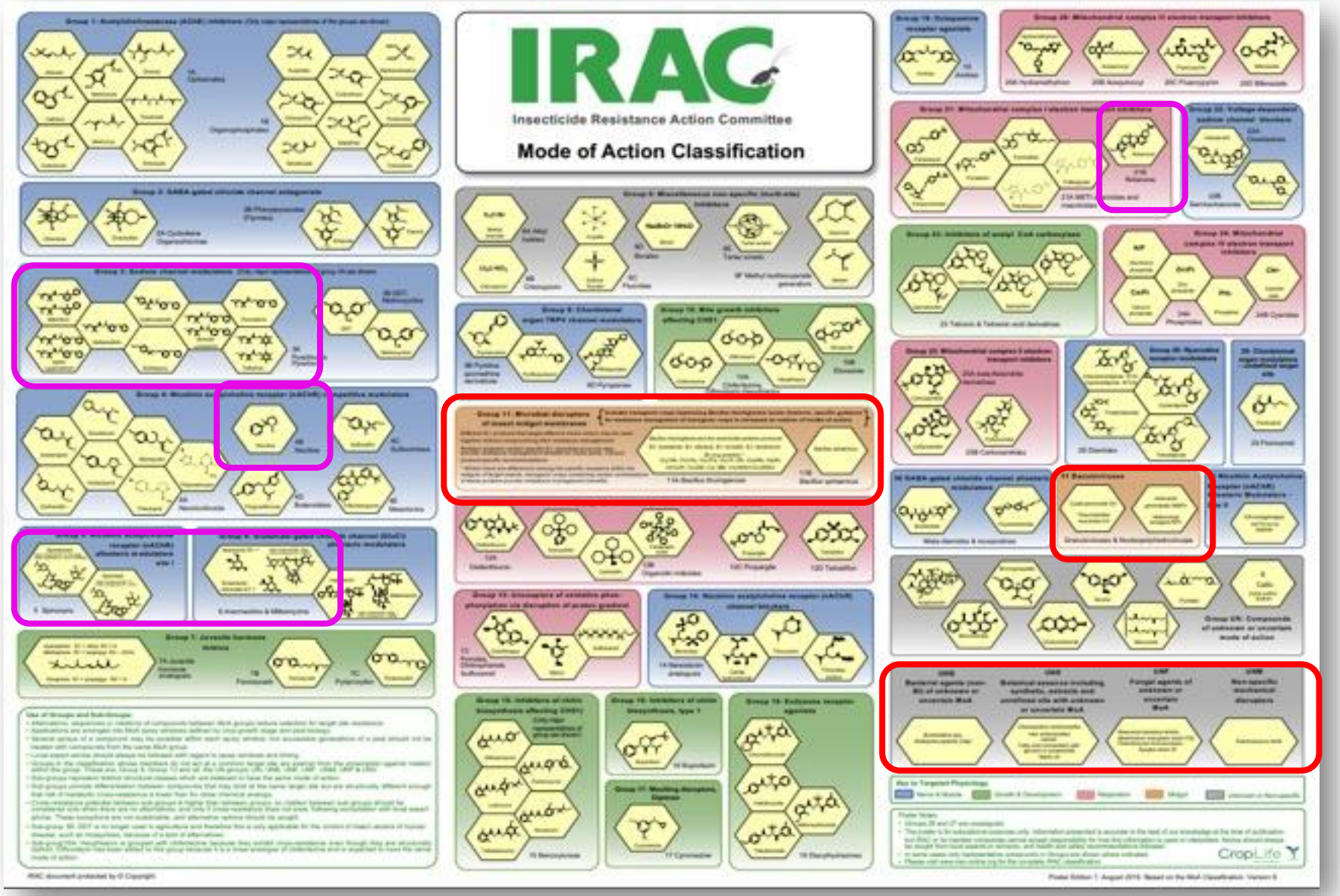
ascribe

Microbe signaling compounds to control fungal & bacterial diseases

Insecticide Modes of Actions

Biological

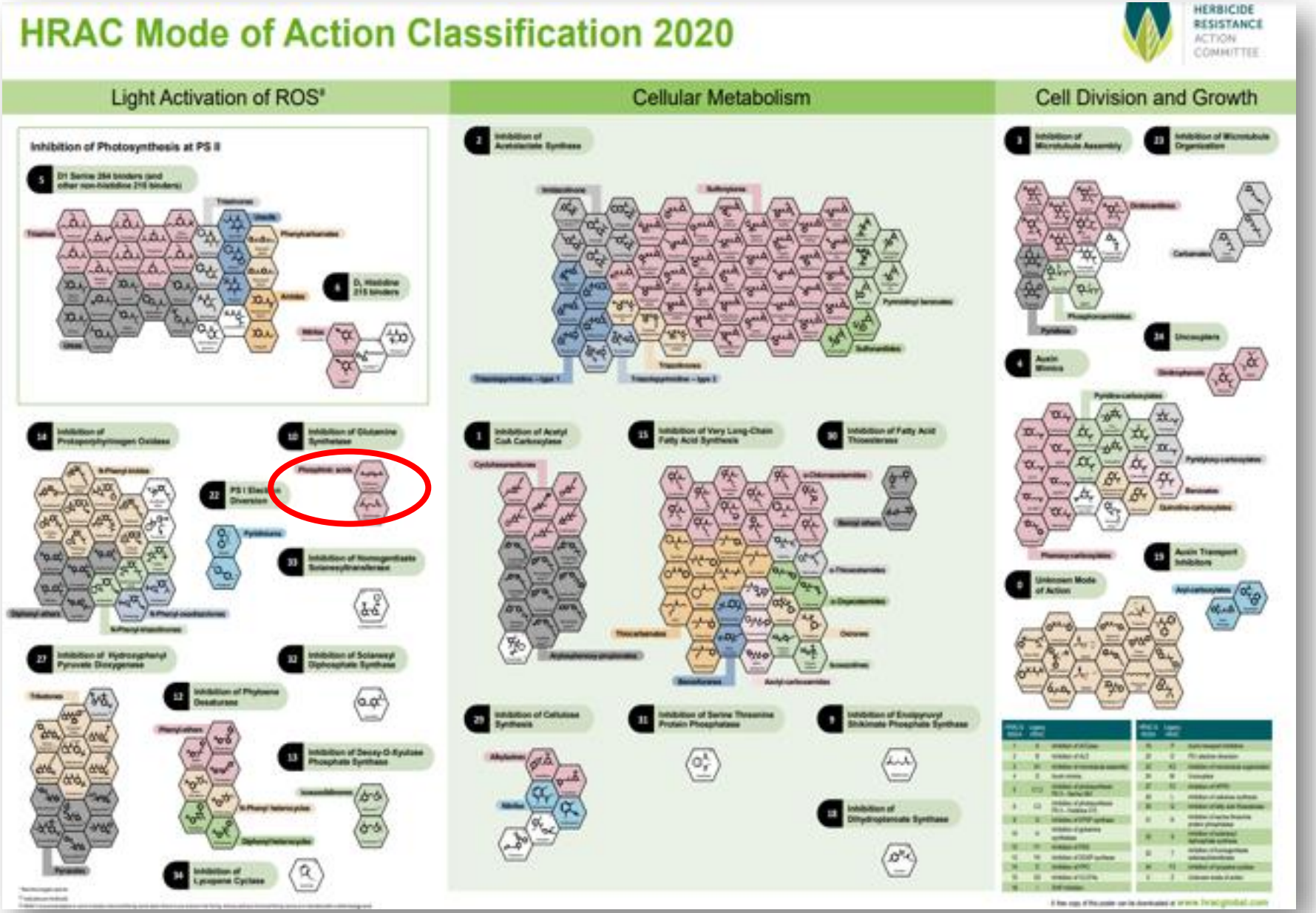
Biologically Derived



Herbicide Modes of Action

No Biologicals

Phosphinic acids: bio-derived

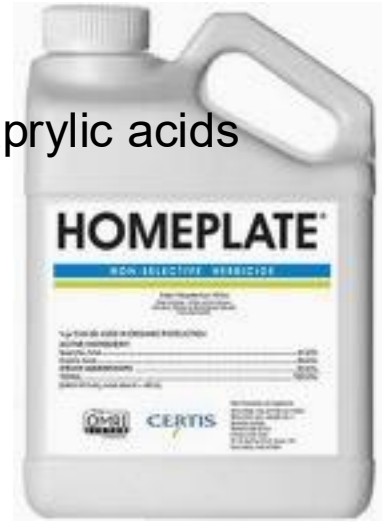


Organic and Other Biologically-derived Herbicides

- Contact
- Non-selective
- Short residual
- High volume
- High cost

Ammonium Soap of Fatty Acids

Capric + Caprylic acids



Citrus Oil

Clove Oil
Peanut Oil
Palm Oil

Pelargonic Acid

Ammonium Nonanoate

NaCl

FeHEDTA

Bioherbicide Research Has Typically Focused on Living Plant Pathogens

Pathogen → Infection

Phytotoxicity

Photo Credit: K. Loeffler and A. Collmer, Cornell University.

Criteria for Competitiveness – a High Bar for Bioherbicides

Systemic	Selective	Reliable > 90% control
Low volume	Low price	Long Residual

HARPE BIO HERBICIDE

ISC

MicroMGX

WeedOUT

micropep

ZUVU BIO SOLUTIONS

THE toothpick PROJECT

APHEA bio

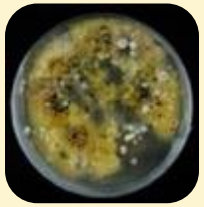
GreenLight Biosciences

moa

- Novel microbes/strains
- Novel compounds
- Directed & high throughput screening
- Synthetic biology
- AI/ML/Genomics tools

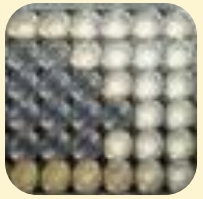
Our AI/ML/Genomics-Led Process to Rapidly Discover & Develop Microbial Natural Products


Source Microbes from the pests' habitats

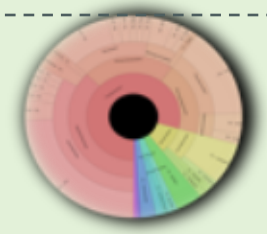



Isolation for highest biodiversity; AI/Genomics mining selection


Natural Product-Based Fermentation


Miniaturized Testing on Weeds & Other Targets as desired



Full Genome Sequencing on all active "hits"

Greenhouse Trials

'Omics Guided-Natural Product Chemistry

Field Trials

ML/'Omics-guided Process Dev & Scale up

ML-guided Formulation

Toxicology & Regulatory

Manufacturing

Total sampling sites till date

60

Total isolates from each sampling site

2,203

Total isolates cryopreserved

2,203

Total isolates sent for sequencing

813

16S

Total isolates analyzed and identified

525

Selected microbes ~60

Active on broadleaves & grasses, pre/post ~20

Advanced 14

Spectrum Testing

We Have Selected Two From 14 Tested

- First is broad spectrum (see weeds tested below) with **both post and pre-emergence activity** (grasses and broadleaves)
- Second **is broad spectrum post emergence activity** on both grasses and broadleaves
- We used bioinformatics to identify gene clusters coding for the possible pesticidal compounds; now embarking on the full pesticidal chemistry ID
- Next: Identify chemistry; field trials and tox testing

Palmer Amaranth

Redroot Pigweed

Watercress

Lambsquarters

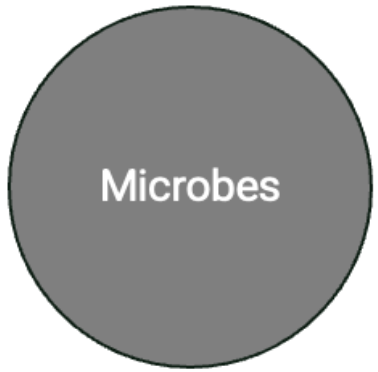
Bermuda grass

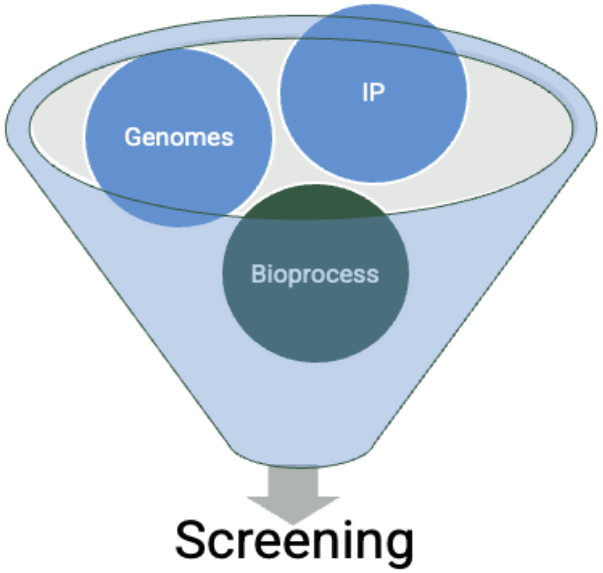
Barnyard grass

Crabgrass

Bluegrass

From Discovery to Product: Development of a Biopesticides is Complex





- Targeted Collection
- Purification and Storage
- Identification-16S
- Literature/database-guided Selection

- Whole Genome Sequencing (WGS)
- Bioinformatics to ID Biosynthetic Gene Clusters (BGC)
- Novel Gene and metabolite ID
- Surrogate target species for Bioassay
- Sample prep with bioactivity localization
- Microbe selection with high IP potential

- Precision Fermentation Process Dev
- Downstream Processing
- RNA Dynamics via Gene Expression Profiling
- Tracking known metabolite pathways (chem.)
- Metabolomics to ID bioactives
- On-line and Off-line Data Monitoring
- Product concentration technology
- Field studies with Whole Plant Scanning, in-situ monitoring
- Iterative formulation tech development

- Regulatory Package
- Microbe ID, Genome
- Process SOPs and Documentation
  - Fermentation
  - Downstream Processing
  - Formulation formats
  - End-product
  - Delivery Technology
- Product Chemistry
- Product Efficacy, Mode of Action
- Toxicology Package

BIOSTIMULANTS
and
BIOFERTILIZERS

The Biofertilizer Market

- **Field Crops** dominate the biofertilizer market, with **71%** of the global market.
- **Legumes** (e.g., soybeans) constitute the predominant market segment, representing **46% of the market**.
- Within legumes, the main crop driver has been **soybeans (34% of the market**).
- **Nitrogen-fixers** have been used historically; this market is maturing. Among Microbial types, **Rhizobia products are the most used (38%) with *Bradyrhizobium* spp. dominating (25%)**.
- ***Bacillus* are the most used after Rhizobia** accounting for 20% of the global market.
- **N-fixers for non-leguminous crops** began their commercial development in the last decade, initially in Latin America with *Azospirillum* and now there are many products.

Many Companies Working on N-Fixing and Nutrient Uptake

COMPANY	PRODUCT(S)	COMMERCIALLY AVAILABLE	ACTIVE(S)
CORTEVA agriscience	Utrisha-N	Yes	*Methylobacterium symbioticum*
PIVOT BIO	PROVEN 40, RETURN, G3	Yes	*Kosakonia sacchari and Klebsiella variicola*
Sound	SOURCE	Yes	maltol lactone + flavenoids
azotic	Envita	Yes	*Gluconocetobacter diazotrophicus*
INTRINSYX BIO	Juno, Rosetta	Yes	*Curtobacterium salicis* and *Pseudomonas siliginis*
TerraMax	MicroAZ-ST	Yes	*Azospirillum spp.*
Koppert	Agriflora PRO	Yes	*Bacillus subtilis & B. amyloliquefaciens*
Kula Bio	Kula-N	Yes	*Xanthobacter autotrophicus*
syngenta	Vixeran, NUELLO® iN	Yes (UK)	*Azotobacter salinestris*
Nutrien	NFINITY	Yes (2025)	Unknown (3-way MoA)
BioConsortia Mosaic	-	Not commercial	*paenibacillus polymyxa*
switch bioworks	NA	Not Commercial	*NA*
JOYN BIO	Bayer Crop Science/Ginkgo Bioworks JV	Not Commercial	*NA*

Upstream

Current National Biostimulant Definition

“Plant biostimulant” means a substance or microorganism, or mixtures thereof, that, when applied to seeds, plants, the rhizosphere, soil, or other growth media, act to support a plant’s natural nutrition processes independently of the biostimulant’s nutrient content.

The plant biostimulant thereby may improve nutrient availability, uptake, or use efficiency, tolerance to abiotic stress, and consequent growth, development, quality, or yield.

Acid-based biostimulants like humic and fulvic acids
Seaweed and plant extracts
Beneficial microbial biostimulants

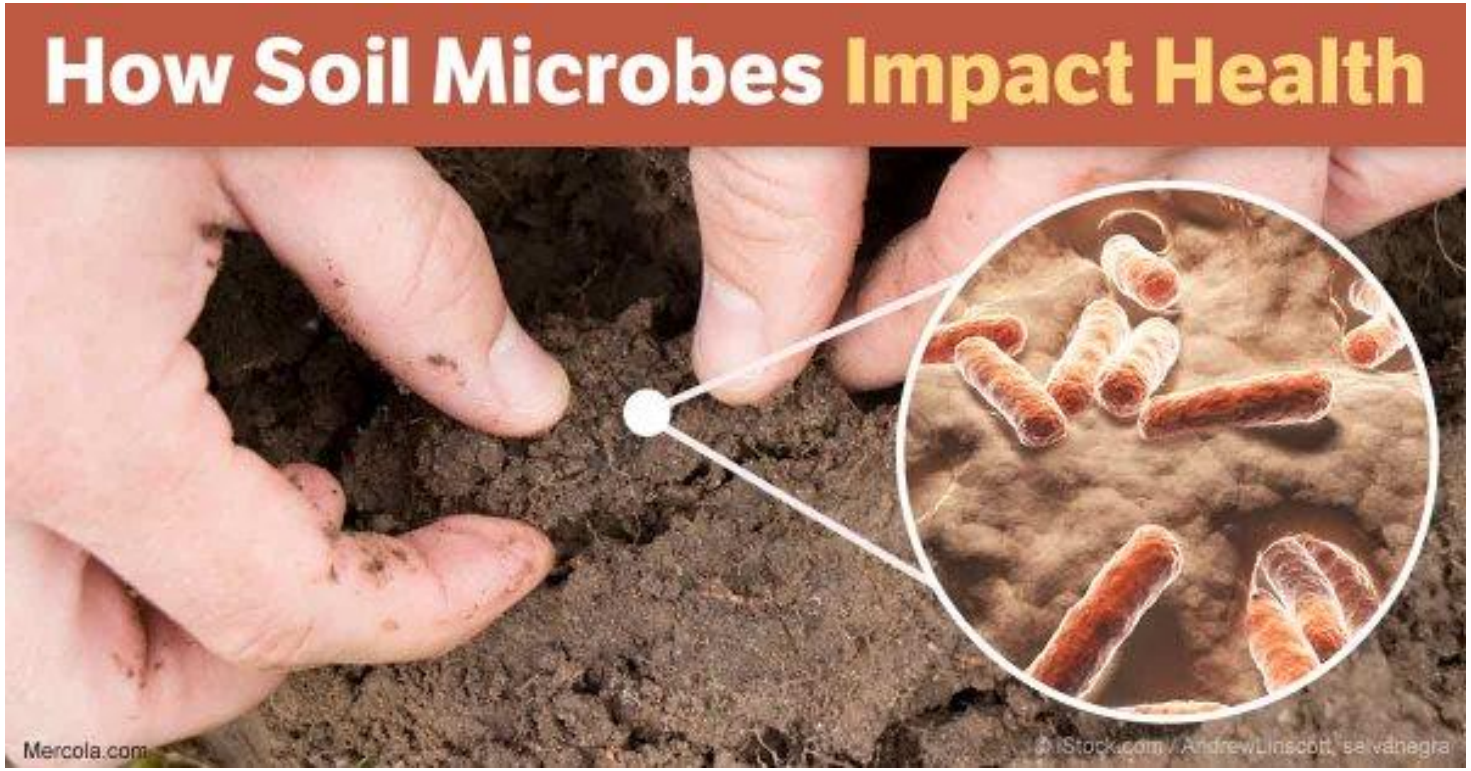
Plant Biostimulant Act Reintroduced in Both House and Senate

The Plant Biostimulant Act would:

- ✓ Amend the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) to define plant biostimulants
- ✓ Direct the EPA to revise the Code of Federal Regulations to reflect the new definition
- ✓ Require the USDA to study the contributions of plant biostimulants to soil health and sustainability

Biologicals and Soil Health

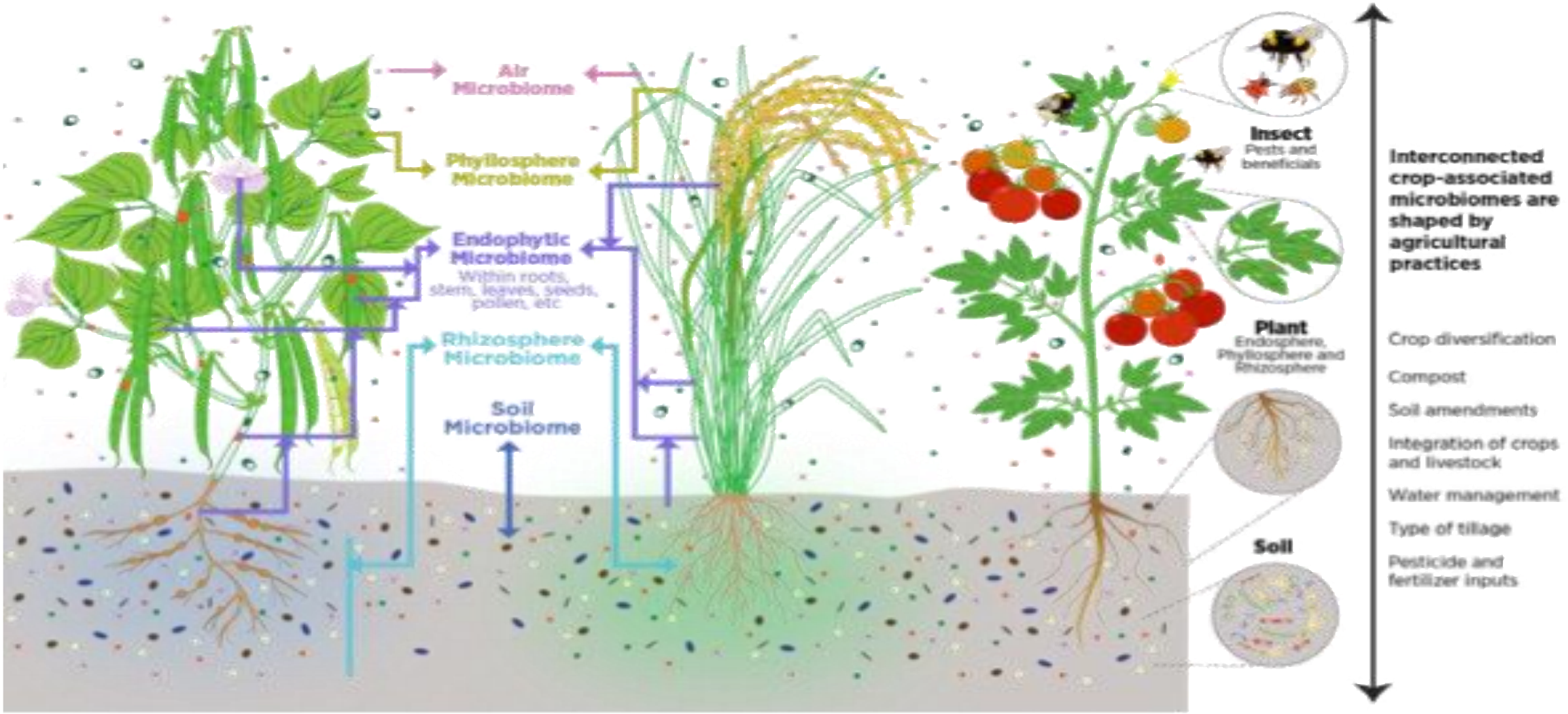
“Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans*”



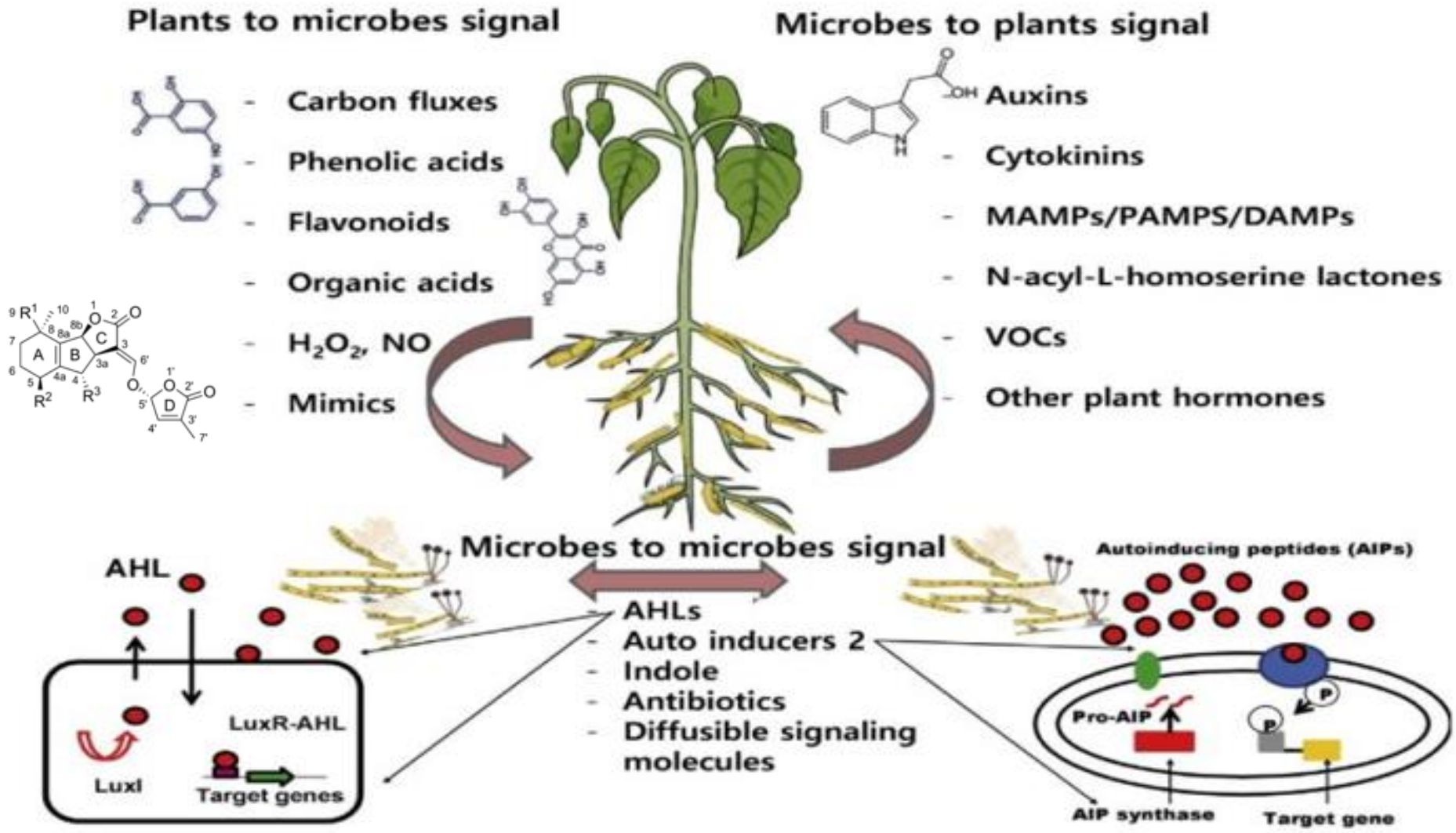
An intense area of interest: Farmers asking crop input suppliers what their products do to soil health

*Lehmann, J., Bossio, D.A., Kögel-Knabner, I. *et al.* The concept and future prospects of soil health. *Nat Rev Earth Environ* **1,** 544–553 (2020). https://doi.org/10.1038/s43017-020-0080-8

Microbiomes are Shaped by Agricultural Practices



Microbes and Plants Actively Signal Each Other



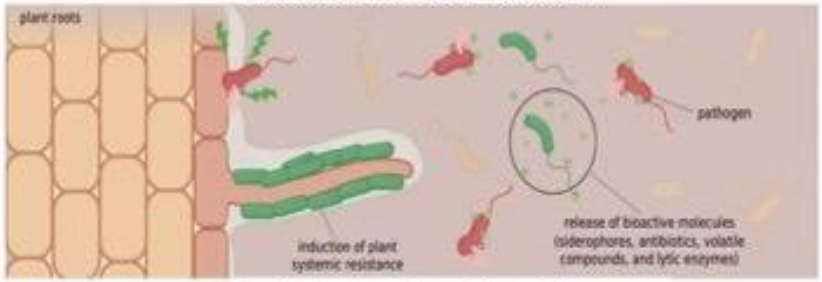
Genes Controlling Mycorrhizal Colonization Discovered in Soybean

Soybean plants growing with and without mycorrhizae.
Photo courtesy of Michelle Pawlowski.

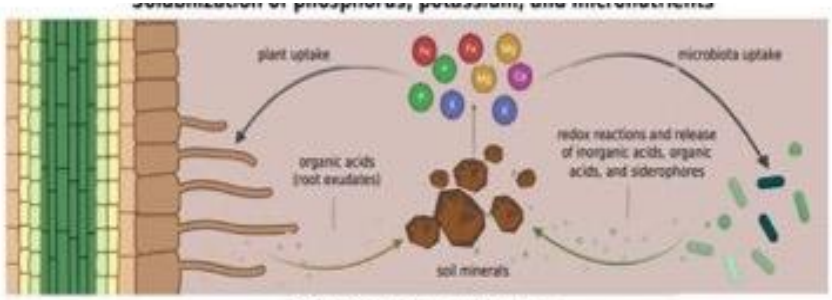
"Whole-genome resequencing identifies quantitative trait loci associated with mycorrhizal colonization of soybean," *Theoretical and Applied Genetics* [DOI: 10.1007/s00122-019-03471-5]. By Michelle Pawlowski, Tri Vuong, Babu Valliyodan, Henry Nguyen, and Glen Hartman. Funding was obtained from the United Soybean Board and the USDA Agricultural Research Service.

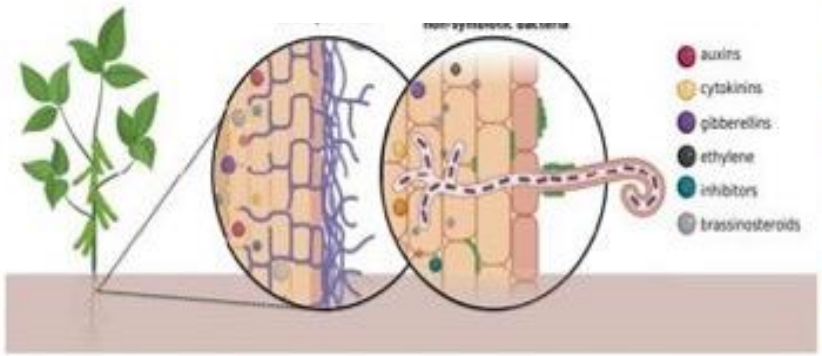
Biologicals Can Have a Positive Effect on Soil Health
Increase Microbial Biodiversity & Shift Functionality

Biological Control of Plant Pathogens/Pests

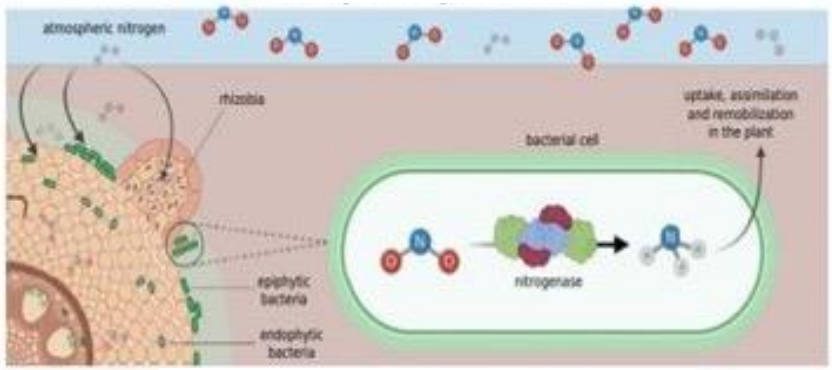


Solubilization of Phosphorous, Potassium and Micronutrients





Production of Plant Growth Regulators
Reduce Sun/Heat and Water stress

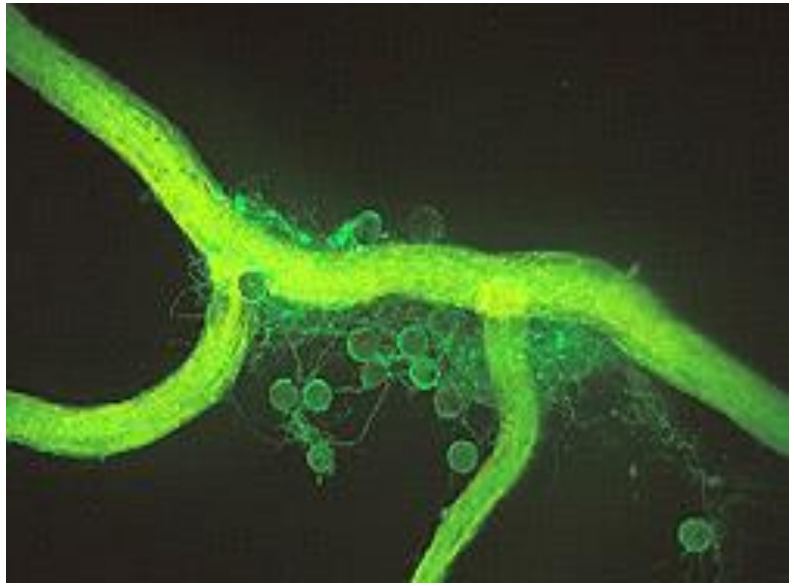


Biological Nitrogen Fixation
Carbon Sequestration

Companies need to have data on what their products are doing to soil health and the microbiome

Mycorrhizal Inoculants are an Effective Method for Carbon Sequestration

- **Glomalin** is unique in its ability to store carbon over decades & can be considered a persistent and stable carbon sink
- Arbuscular Mycorrhizal Fungi (AMF) are the only known source of glomalin, and are in fact its namesake
- Once recognized as an acceptable method of carbon sequestration, farmers should benefit from carbon credits



Glomalin, dyed green, shown to completely cover mycorrhizal corn root and fungal spores
Photo by Sara Wright

Groundwork BioAg

3 Ways To Enhance No-Till Farming With Biologicals

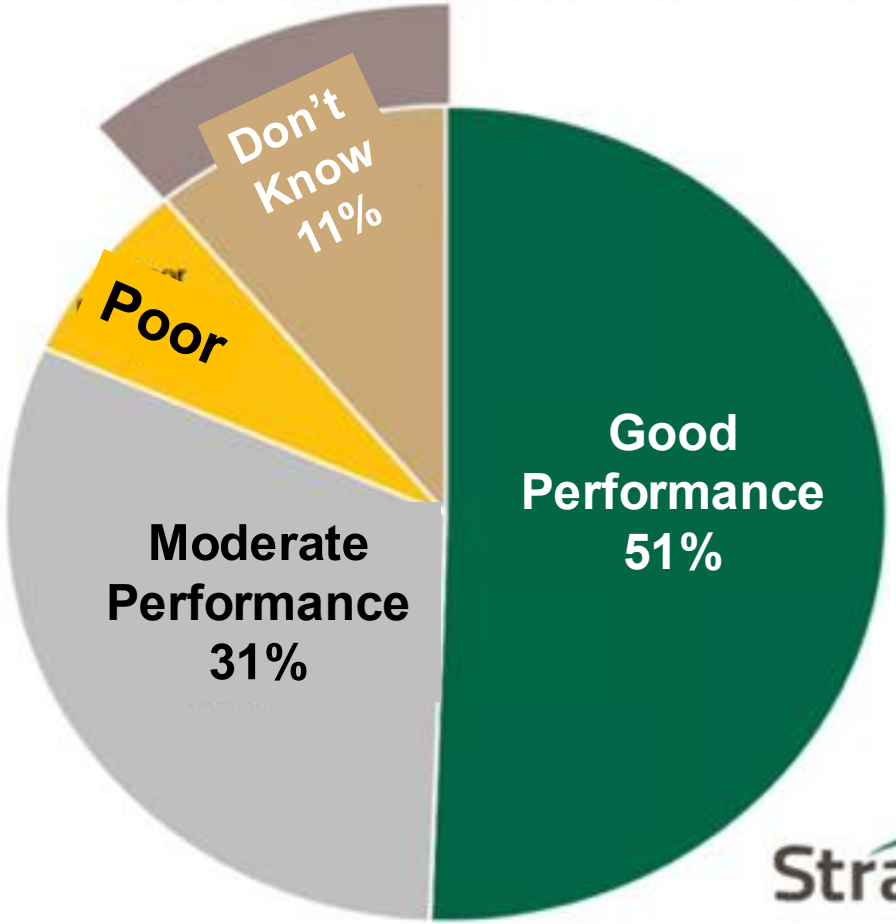
1. **Accelerated Growth in Cooler Soils:** Biological products containing beneficial microbes can accelerate early season root growth and vegetative development, giving a boost right after planting.
2. **Expanded Root Systems to Access Nutrients:** The beneficial microbes in biologicals colonize the root system and support expanded lateral and vertical root growth. This allows crops to access more nutrients and moisture deeper in the soil profile.
3. **Potential to Translocate and Cycle Nutrients Deeper into Soils:** Biologicals that contain endophytic microbes – microorganisms that enter into and live within plant tissues – have the potential to translocate and cycle nutrients deeper into the root zone where they are more available to the crop.

Adapted from Locus Ag

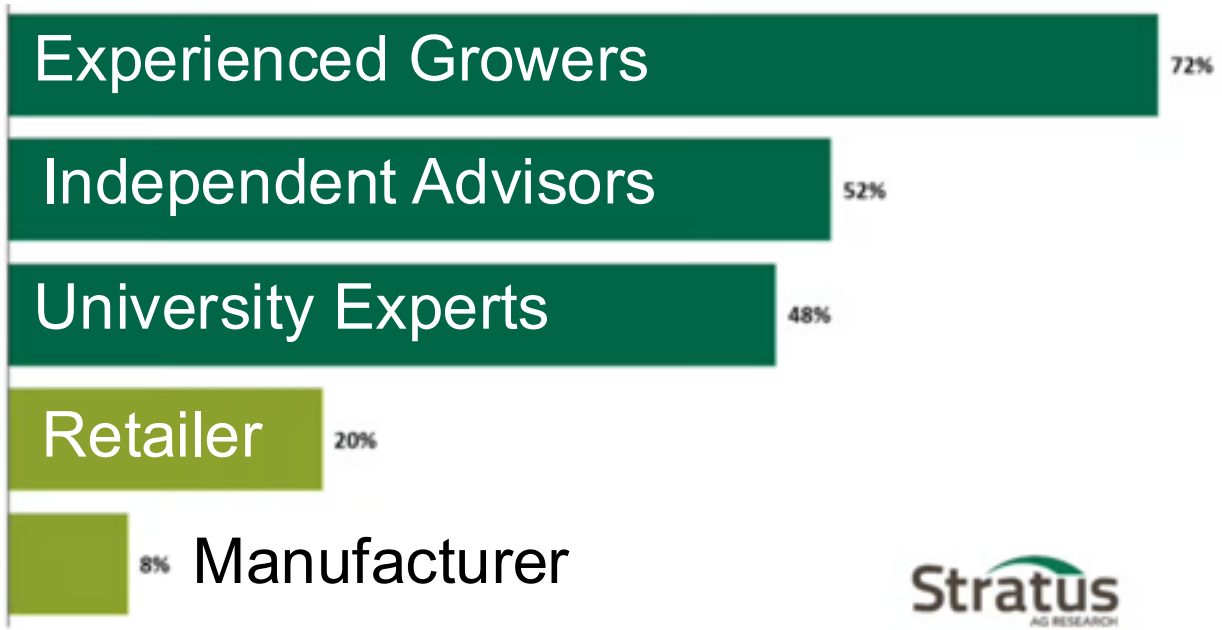
What do Farmers Think About Biologicals?

Stratus Survey on Biostimulants
Nice to have but not essential for US Growers

Retailer Assessment of Biostimulant Brand Performance



Sources of Biostimulant Information % ranked #1 or #2



What Did You Like Best About Your Experience With Biologicals?

- Ease of use and the boost in yield were the best aspects of using biologicals

CURRENTLY USE

What Did You Like Least? N=185

- The cost and the extra work were the most maligned aspects

CURRENTLY USE

(ONLY if answered NO in Used Biological in the Past) Why Have You Chosen Not To Use Any Of These Product Types? N=270

- Producers who have never used biologicals believe they are not proven, or have a lack of knowledge on the subject

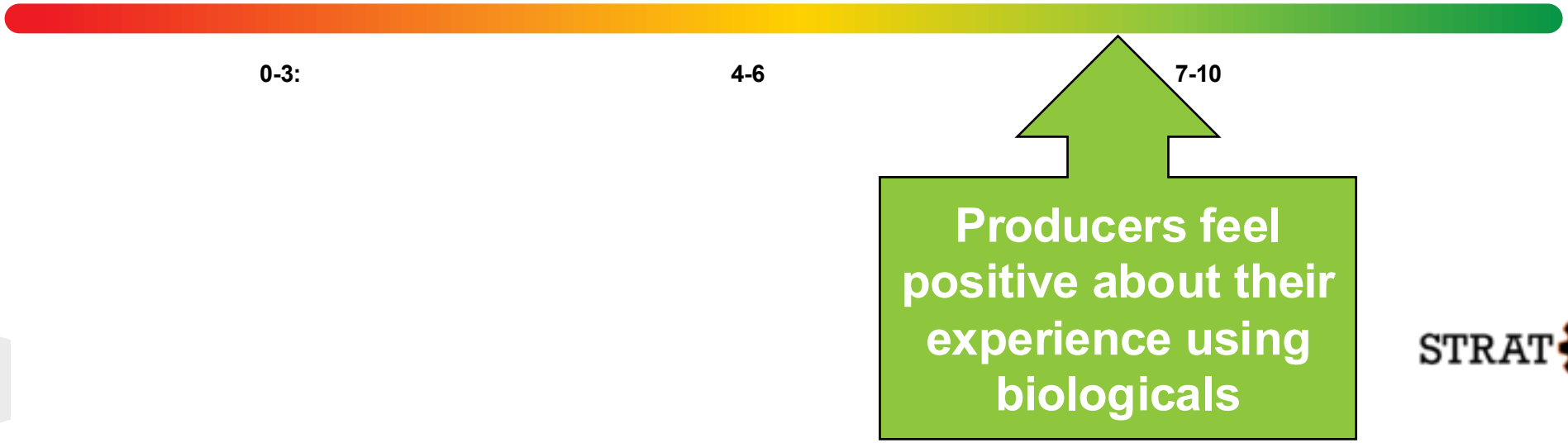
NEVER USED

When Farmers Learn How to Use Biologicals, They Score Them Highly

Biological user-farmers rate their experience with biologicals a 7.14/10, showing a positive perception

CURRENTLY USE

On a scale of 0-10, with 0 being “terrible” and 10 being “fantastic” how would you rate your experience with biological products? N=185



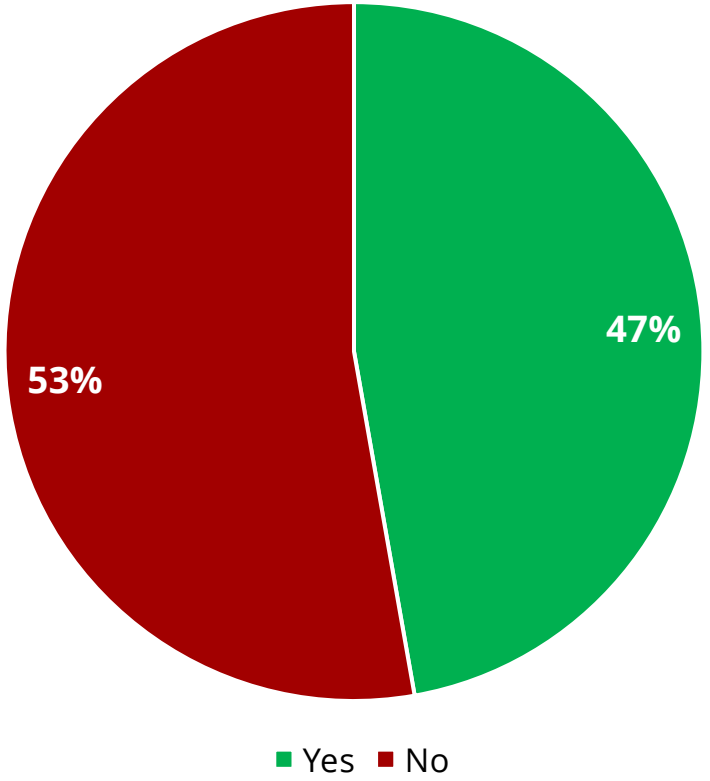
STRATOVATION GROUP

Have you been educated about biologicals? Such as the benefits, limitations, or available options?

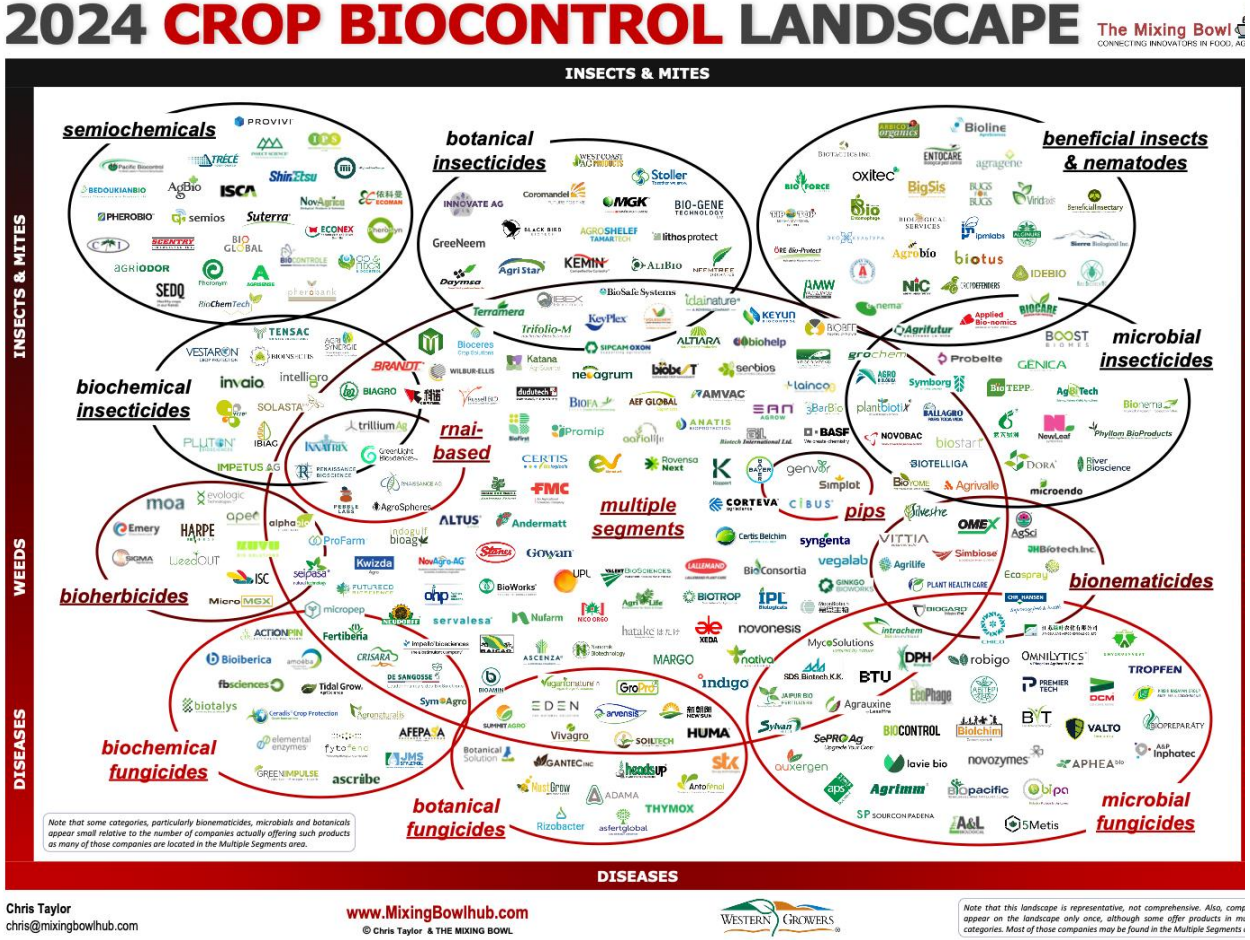
Overall

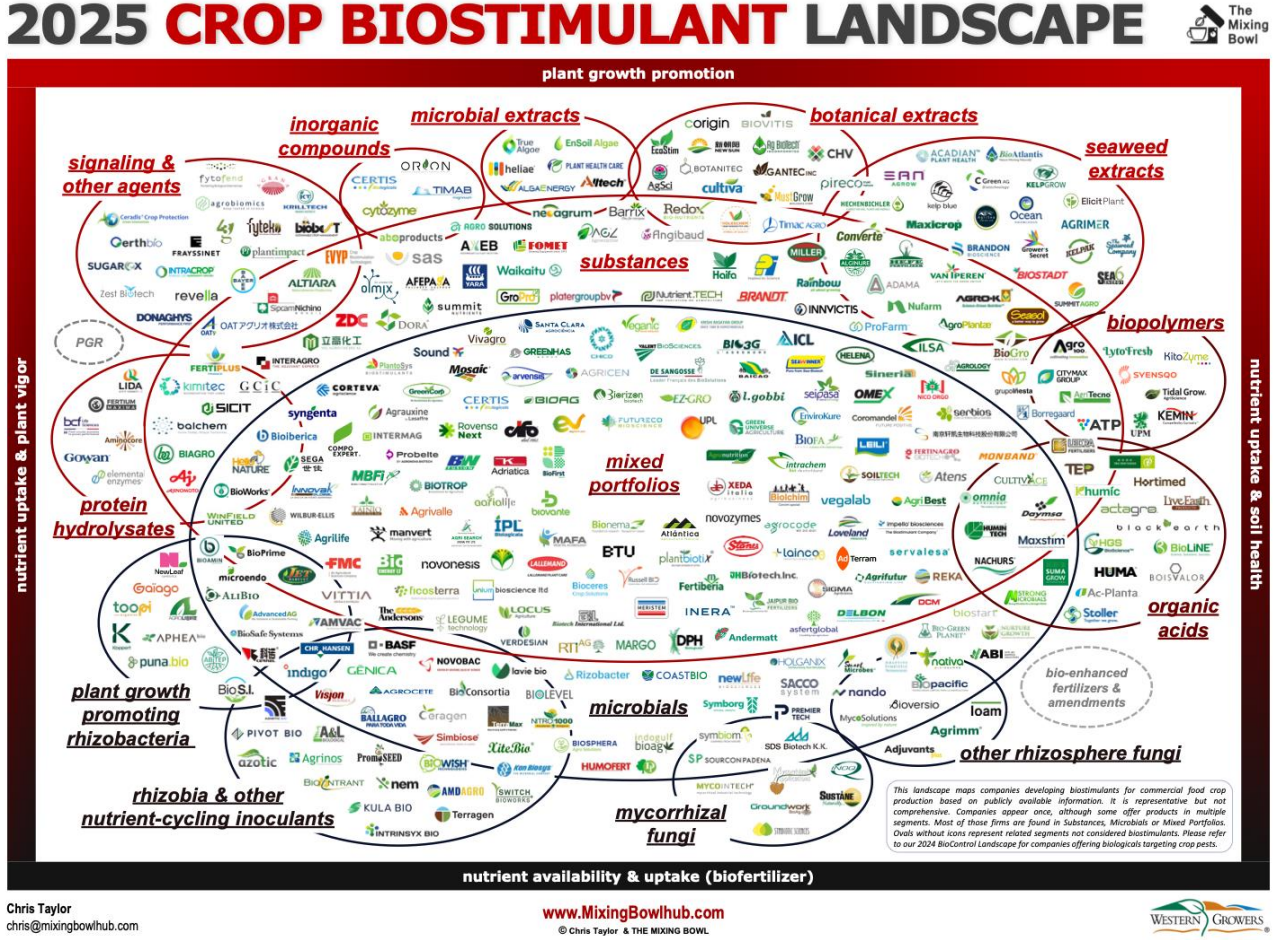
Education on biologicals is still lacking and is one of the major things holding acceptance back

EDUCATION
EDUCATION
EDUCATION



In any survey, the percentage of farmers who say they they are not educated about biologicals has remained at ~50% **for the past 5 years**





It's crowded and can be overwhelming to understand!

New Entrants Need to Have Differentiated Technology With Clearly Articulated Competitive Advantages

Fill an Unmet Need!

NCAT ATTRA SUSTAINABLE AGRICULTURE

https://attra.ncat.org

American Society of Agronomy

https://www.agronomy.org

Upstream

https://upstream.ag

SOIL HEALTH INSTITUTE

https://soilhealthinstitute.org

AgFUNDER

https://agfunder.com

Marrone PG (2025) Increasing the use of biological pesticides in integrated pest management programs. Frontiers of Insect Science 5:1552361. https://doi.org/10.3389/finsc.2025.1552361